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ABSTRACT

This manual is intended to guide developers, site planners, and builders in designing residential developments so that access to sunlight is maintained for planned or potential solar collectors. Almost any housing development can be designed to facilitate the use of solar energy. Differences are not in costs but in planning. Described in this guidebook are the major elements of planning a housing site to protect solar access. These developments are: (1) site selection and analysis, (2) preliminary site planning, (3) general design approaches and techniques, (4) specific design strategies, (5) landscaping and plantings, and (6) covenants and easements. Also presented are two case studies which demonstrate the application of approaches and techniques discussed. Over 100 figures and tables supplement the written material. (WB)

Site Planning For Solar Access:
A Guidebook for Residential Developers and Site Planners

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This guidebook is one of a three-part series of manuals on solar energy and solar access prepared by the American Planning Association for the U.S. Department of Housing and Urban Development. The APA is a consolidation of the American Institute of Planners and the American Society of Planning Officials.

The other two guidebooks in the series are:

Protecting Solar Access for Residentiel Development: A Guidebook for Planning Officials, by the APA.

Solar Design Review: A Menual on Architectural Controls and Solar Energy Use, to be completed by the APA.

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On two separate occasions after preliminary drafts were completed, a group of twelve came to Chicago to review the drafts. The review session participants were: Christopher M. Blanton of Stolar, Heitzmann and Eder, St. Louis, Missouri; Gilbert Finnel, Jr., School of Law, University of Houston, Texas; Gail Hayes, Environmental Law Institute, Washington, D.C.; Tudor Ingersoll, MassDesign, Cambridge, Massachusetts; Lane Kendig, Lake County Regional Planning Commission, Waukegan, Illinois; William Northrup, Indio Planning Office, Indio, California; and Larry Reich, City of Baltimore, Department of Planning, Baltimore, Maryland. In addition, members of the development community also offered their comments, suggestions, and criticism on earlier drafts, to assist us in writing a better report. We wish to thank Jay H. Feldman, Assistant Director of the National Housing Center of the National Association of Home Builders, Washington, D.C.; Ralph J. Johnson, President of the NAHB Research Foundation, Incorporated, Washington, D.C.; Durwin Ursery, Urban Investment, Incorporated, Chicago, Illinois; and Dick Wirth, Building Industry Association of Southern California, Los Angeles, California.

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Introduction

This manual is intended to guide developers, site planners, and builders in the design of residential developments for solar access. Planning for solar access means laying out buildings, roads, landscaping, and open space so that solar collectors, whether actually in place or merely planned for the future, can get direct sunlight to permit the use of solar energy for space heating, water heating, or air conditioning. Proper site planning for solar access today opens the way for the use of solar energy tomorrow.

Site planning for solar access uses the same design elements as conventional development but may organize them differently. In a solar development, for example, the streets are basically the same as in a conventional development, but they must be oriented properly toward the sun. Similarly, both conventional and solar developments require open space; in a solar development, however, the open space must be located to prevent shading of the collector. There are no differences in cost, only in planning.

Site planning for solar access need not be complicated or expensive. Almost any development can be designed to protect solar access and promote solar energy use. Although only a few solar developments have been built to date, the evidence shows that the site preparation, development, and construction costs associated with them need not be more expensive than those for conventional developments. In most cases it is possible to provide the same number of solar-heated or cooled dwellings on a given site as would be possible under conventional single-family or multifamily development. Paving, grading, and infrastructure also are about the same as those for conventional developments.

Solar developments also can be designed to fit the constraints of most conventional land-use controls, ordinances, and regulations. (A companion guidebook for the U.S. Department of Housing and Urban Development (HUD) by the American Planning Association, *Protecting Solar Access for Residential Development: A Guidebook for Planning Officials*, examines the situations where local ordinances must be changed.) With the exception of regulations that bar the installation of solar equipment on a structure, most current local regulations can readily accommodate solar developments. Several states (notably California, Oregon, and Minnesota) have even passed laws requiring that local communities plan for and promote solar energy use. State and federal tax laws also provide major incentives for the use of solar energy.*

In states without such legislation or where local regulations pose barriers to solar access design, the developer can consider flexible development techniques, such as planned unit development (PUD) or mixed use development (MXD) provisions. Local governments often welcome such innovative proposals, particularly in the case of something as new and important as solar access. In any case, the developer or builder should be aware of applicable energy-conservation or solar energy codes or statutes and take advantage of them whenever possible.

This manual also makes some assumptions about the skills and interests of developers and site planners. First, it assumes that the developer already has a great deal of experience and knowledge about designing and building housing developments. Therefore, it concentrates on protecting solar access and for the most part, ignores the more general site planning practices and procedures affecting both solar and conventional developments. Second, this manual presumes a basic knowledge of solar technology (such as the uses of active and passive systems) and its application to residential structures. While it does mention certain types of solar technology (see the Appendix and the Glossary), it is not a substitute for the expertise of an architect or solar designer who is familiar with these matters. In using some of the design strategies discussed in this manual, the developer or site planner is presumed to have made some of the technical decisions involving solar energy use and application. Finally, this manual does not discuss in detail other aspects of energy conservation (such as landscaping) except insofar as such techniques affect solar access.

*National Solar Heating and Cooling Information Center. *State Solar Legislation.*

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Figure 1. Flashlight Analogy to Solar Radiation

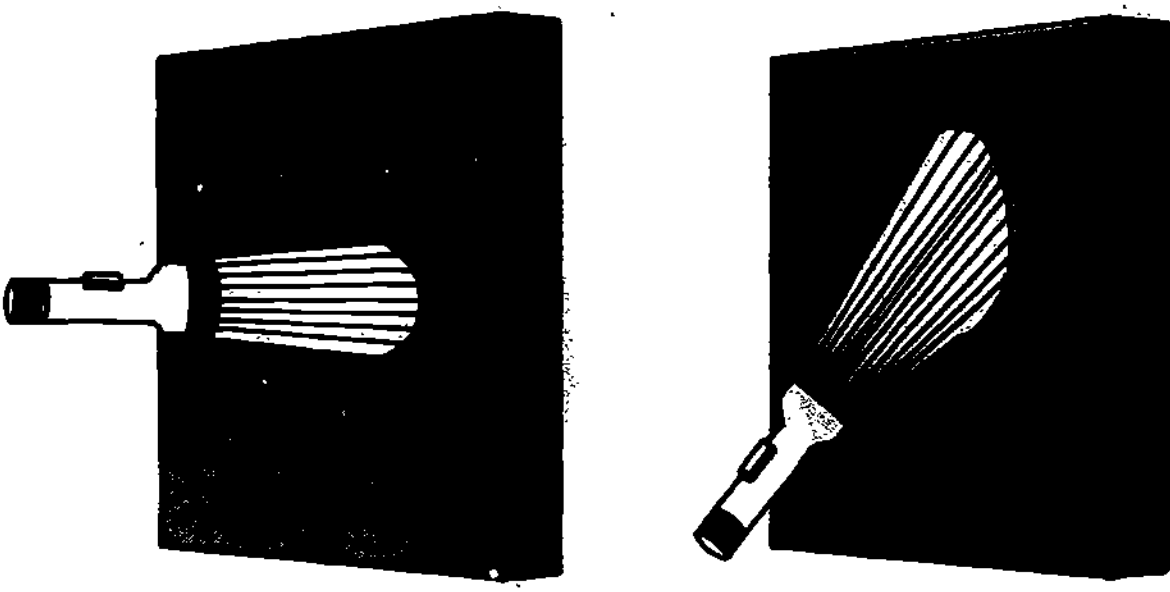
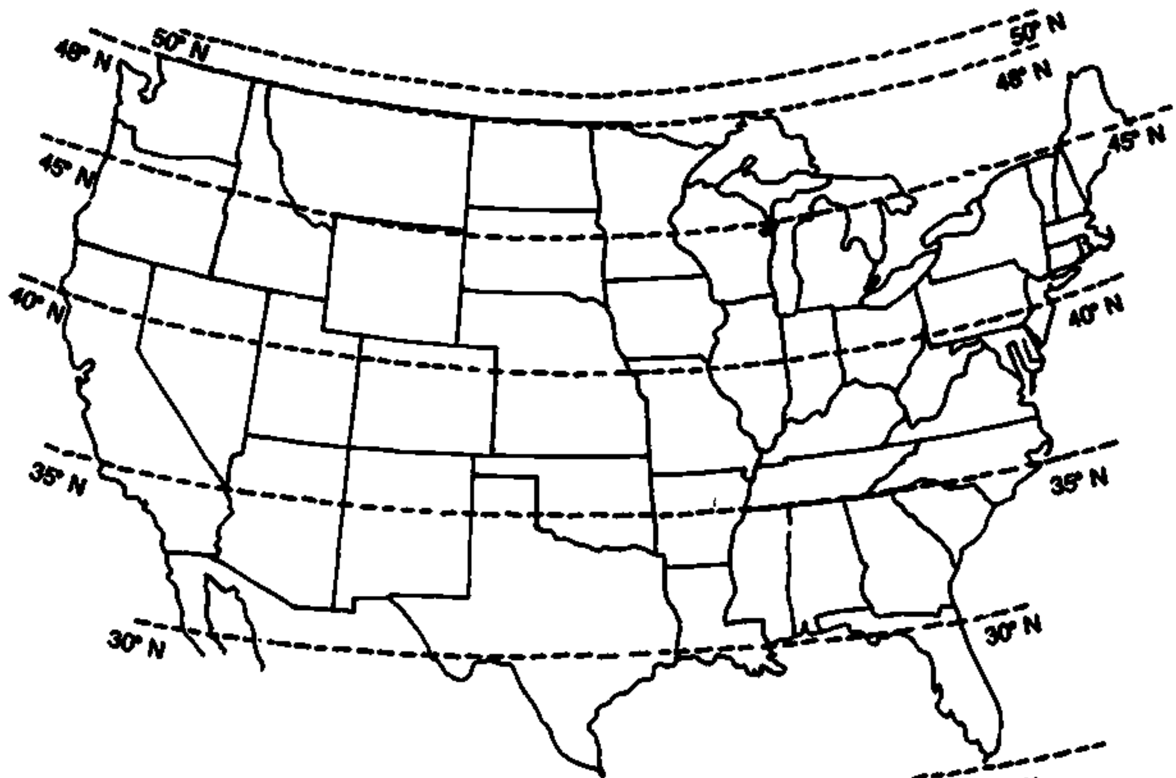


Figure 2. Latitudes of the Contiguous 48 States



Because the earth is tilted on its axis, the altitude of the sun at a given location depends on three factors: the time of day, the latitude, and the season.

Common sense shows that the sun's light is most intense at solar noon, when it reaches its high point in the sky for the day, and it is weakest at sunrise and sunset, when it is tilted away from the site's position on the earth's surface. The second factor, latitude, or the distance north or south of the earth's equator, also affects the sun's position in the sky. Because of the earth's curvature, the farther north one goes in the northern hemisphere, the lower the sun appears to be in the sky and the less its intensity. Finally the change of seasons also affects the intensity of sunlight, particularly in latitudes distant from the equator. If the earth's axis were perpendicular to the plane of the earth's orbit around the sun, there would be no change of season. Since the earth's axis is tilted at about 23.5 degrees from the perpendicular, the northern hemisphere is tilted slightly toward the sun in summer and slightly away from it in winter. (The situation is reversed, of course, for the southern hemisphere.) Because the sun's rays are more nearly perpendicular to the site in summer than in winter, it is hotter in summer than in winter.

Although the sun's position in the sky changes from minute to minute, season to season, and latitude to latitude, its position at any one time can be determined by using two measurements, altitude and azimuth. *Altitude* is the distance, measured in degrees, between the sun and the horizon—0° at sunrise and sunset, to a maximum of 90°. *Azimuth* is the distance, measured in degrees, of the sun relative to due south. It is expressed as a negative value to the east and as a positive value to the west. (It can also be measured from the north, using 360 degrees, but that method is not used here.) The sun's azimuth is greater in the summer than in winter because the sun rises and sets farther north in summer. Figure 4 shows how altitude and azimuth are measured. Figure 5 shows the path of the sun at 40° north latitude during the solstices—that is, the days when the longest (summer) and shortest (winter) periods of sunlight occur.

Figure 3. The Intensity of Sunlight Decreases with Latitude and Season Because of the Tilt of the Earth

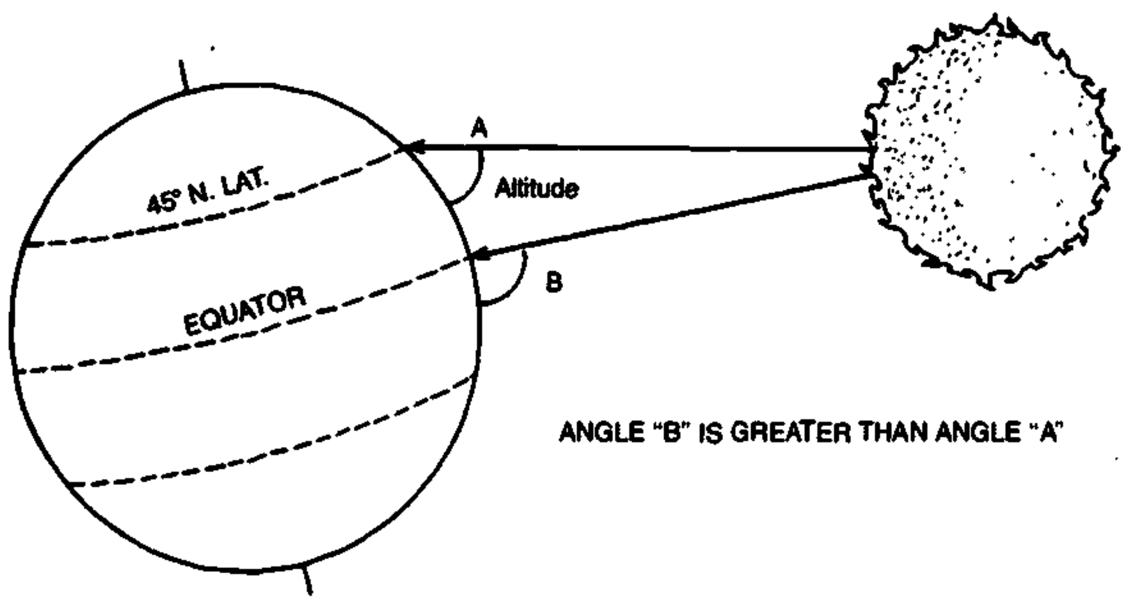


Figure 4. Azimuth and Altitude

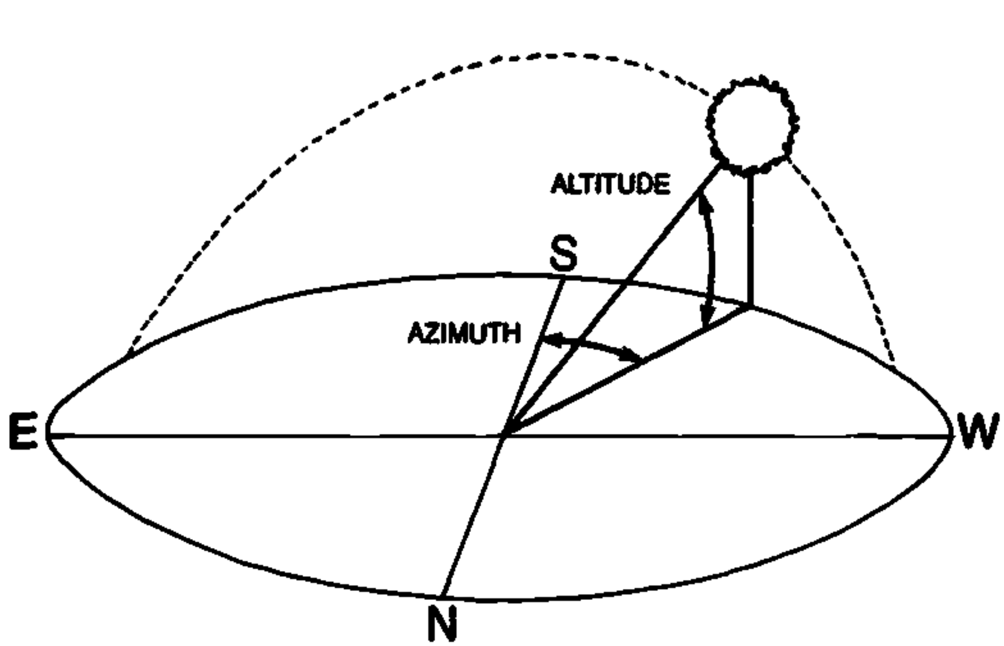
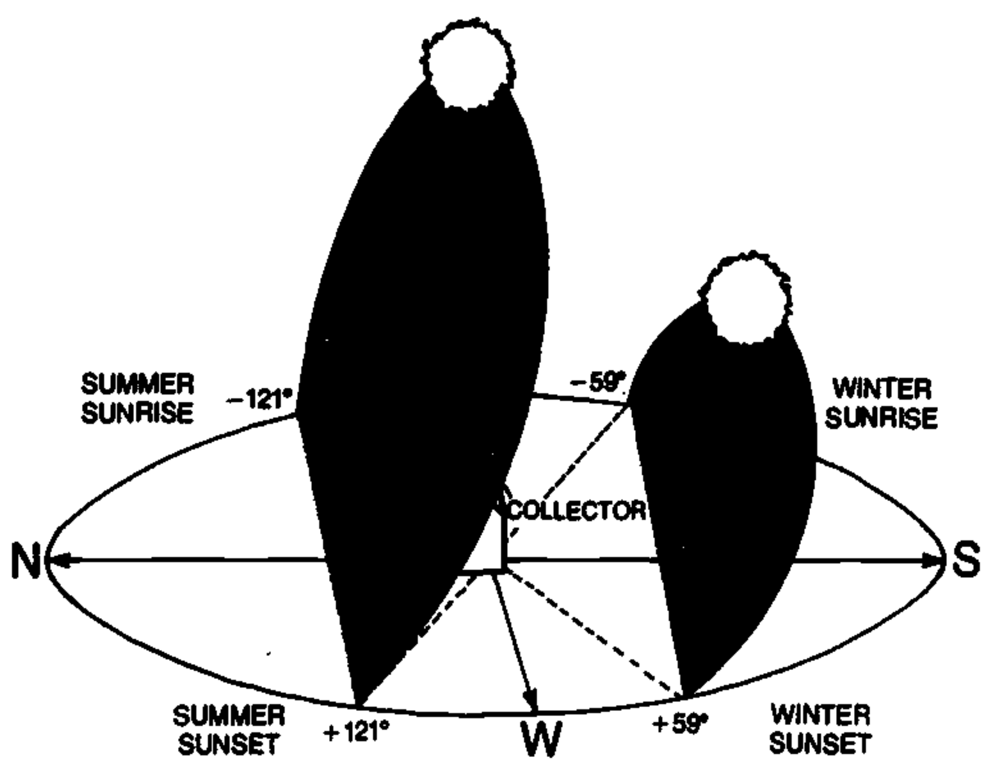


Figure 5. Winter and Summer Sun Paths



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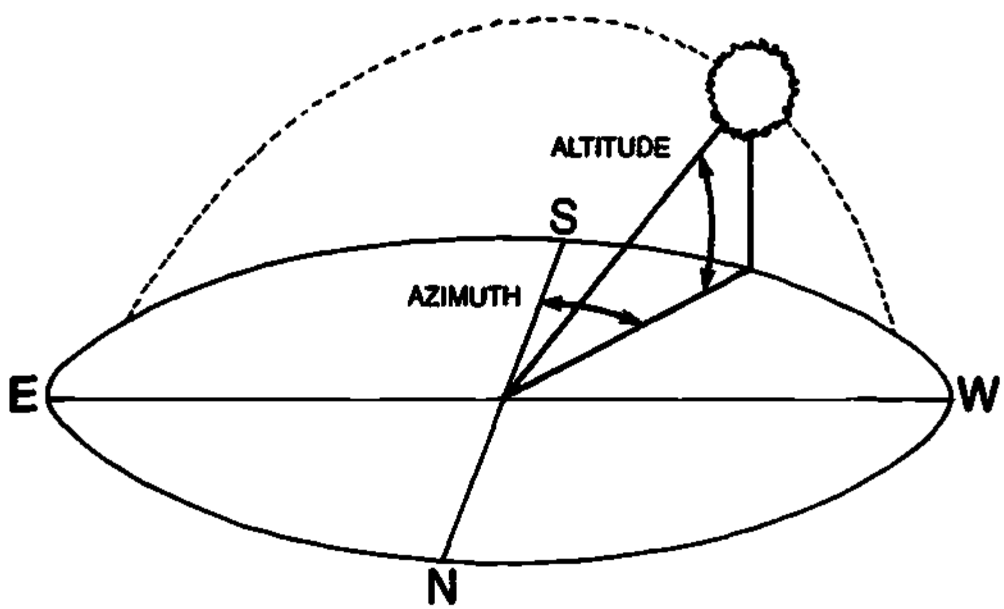

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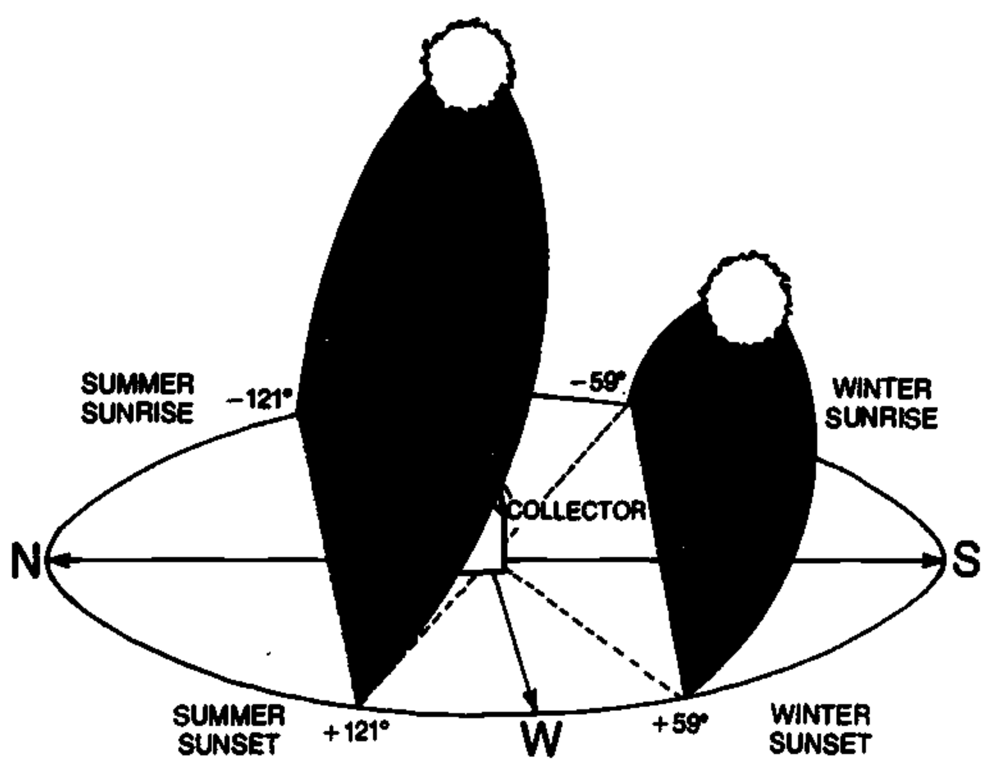
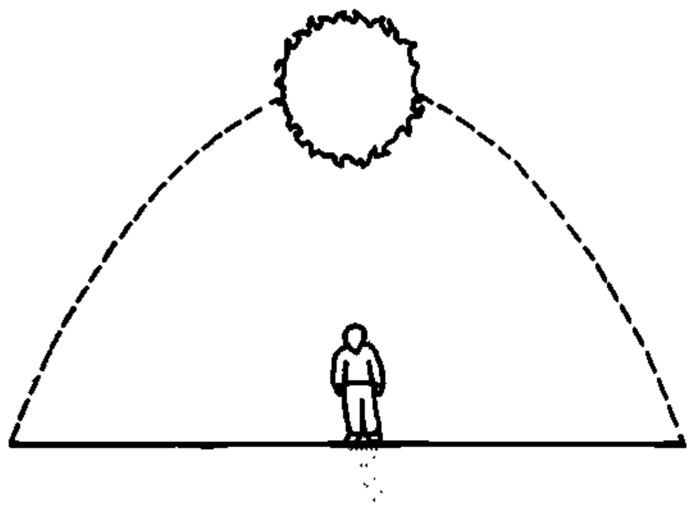
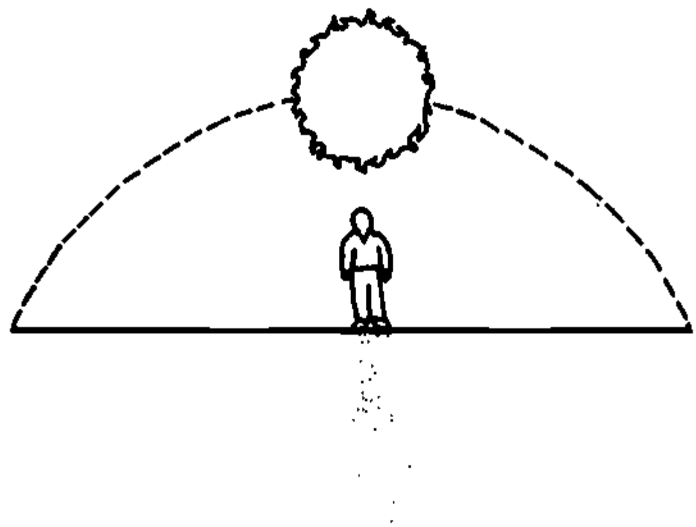


Figure 6. The Sun Is Lower in the Sky and the Shadows Longer in Winter



SUMMER



WINTER

Recalling the flashlight analogy, it is now clear that the sun is less intense in the morning and afternoon hours because it is at an oblique angle to the earth's surface. This phenomenon also accounts for the lesser amount of solar radiation available in winter, when the earth's tilt lowers the apparent position of the sun in the sky. Finally, it explains why less solar radiation is available at higher latitudes. Because of the earth's curved surface, the sun appears lower in the sky and solar radiation is more oblique to the earth's surface. Thus, the sun's daily and seasonal position is crucial to site selection because areas perpendicular to the sun's rays receive more solar energy than areas oblique to sunlight.

Having reviewed these facts, it is now possible to turn to the methods for assessing the availability of sunlight on a given site.

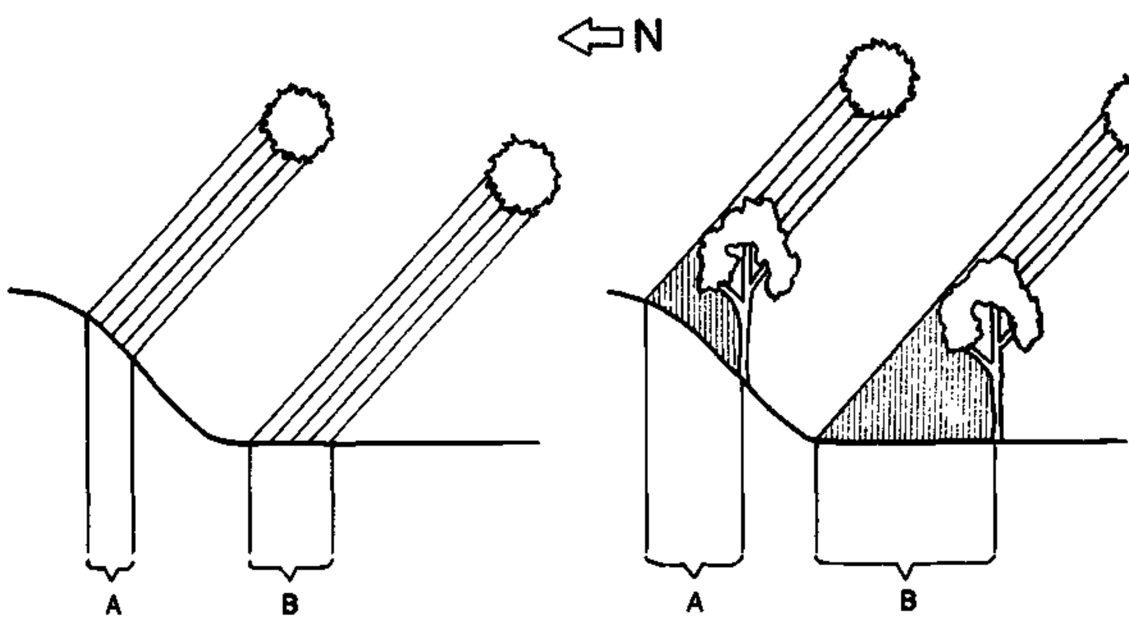
Latitude and Topography

The latitude and topography of a site affects both the availability of sunlight and the length of shadows cast by objects on the site. At higher latitudes, the sun is lower in the sky, creating longer shadows. Likewise, changes in topography affect the angle at which the sun hits the ground. On south slopes, as at lower latitudes, sunlight is more nearly perpendicular, so shadows are shorter than on flat land or on a north-facing slope. More solar radiation is also available on south-facing sites, as figure 7 illustrates.

In the northern hemisphere, south slopes are optimum for solar energy use. Because the sun is in the southern sky, south slopes are most nearly perpendicular to the sun's rays, and therefore can capture a greater amount of winter solar radiation than other slopes can.

The greater amount of solar radiation and the shorter shadow lengths make it easier to plan for solar access protection on these slopes than on many other areas of the site. Because of the shorter shadow lengths, buildings can be sited closer to one another without obstructing solar access, and higher densities may be possible.

Figure 7. Radiation and Shadow Length on a South Slope



Area of ground receiving the ray on flat ground (B) is larger than area on south slope (A). Thus more energy is received per unit area on the slope.

Shadow cast by tree on flat ground (B) is longer than the one cast by same tree on south slope (A).

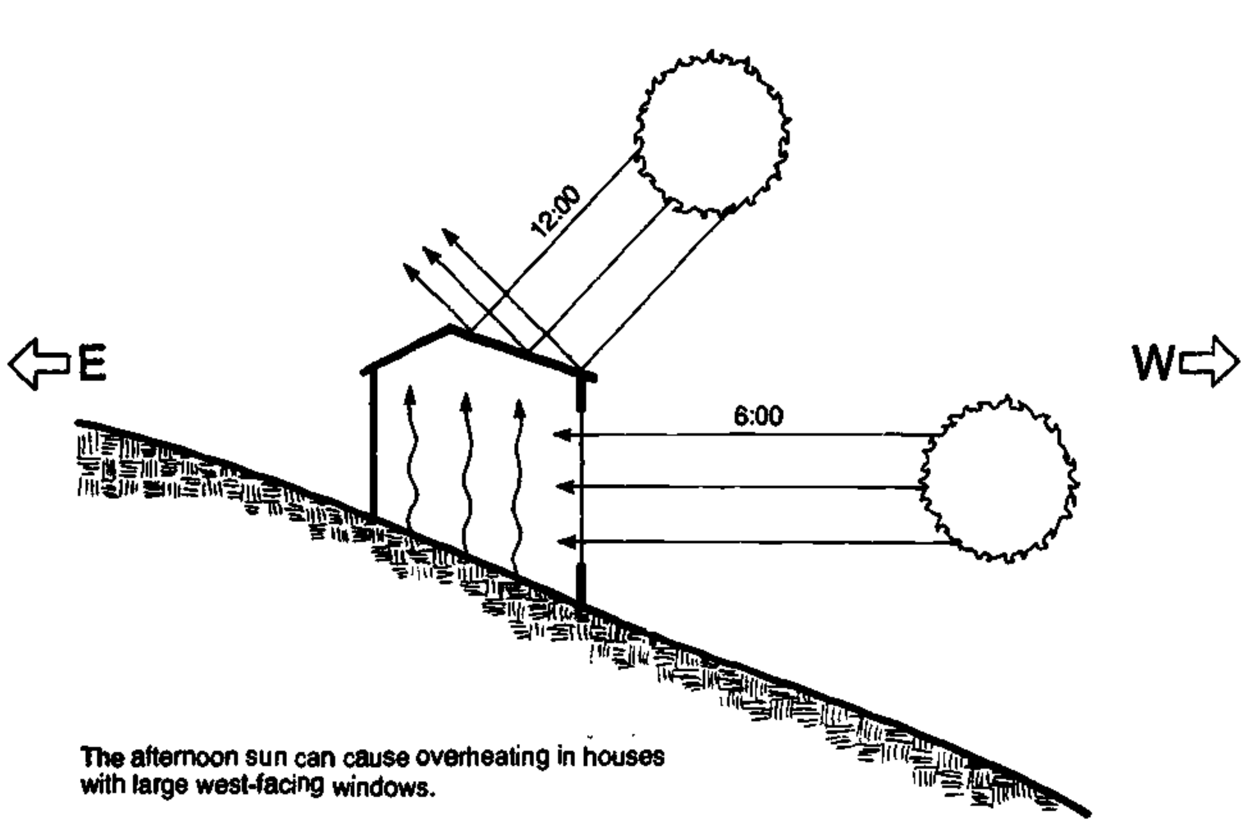
Because south slopes absorb more winter solar radiation, they tend to be warmer than other places on a site and therefore have more moderate temperatures in cooler climates during the winter. With winter temperatures moderated, less energy (whether solar or conventional) is needed to maintain comfortable temperatures in structures located in these areas.

Other slopes are less ideal for solar access and solar energy use. East and west slopes get more sunlight in summer and less in winter than south slopes. The sun rises far to the north in summer, striking east and west slopes almost perpendicularly. This can cause overheating of buildings in summer, particularly if the structures have large window areas on the west and east walls. Overheating is a particular problem in the late afternoon, when the west side of a building is exposed to afternoon sun. If a building is adequately shaded in summer, however, east and west slopes can still be suitable for solar development.

North slopes are the least ideal for solar access and solar energy use. Shadow lengths are extremely long, making site planning difficult if solar access is to be preserved. The oblique solar angles mean that the slope tends to be colder in the winter months. In those climates with predominant north winter winds, these slopes are also more exposed, and buildings are more apt to lose heat than those in sheltered locations.

Energy availability and shadow length also vary with slope gradient. The steepness of a slope accentuates the conditions created by slope direction. In other words, if south slopes are warmer than other slopes and have shorter shadows, then steeper south slopes will be warmer still and have even shorter shadows. Similarly, if north slopes are cooler, they will be even colder if slope gradient increases. Figure 9 shows a comparison of all four slope directions on radiation gain and shadow length for an object 10 units tall on a hypothetical site with two different gradients.

Figure 8. Building Overheating



The afternoon sun can cause overheating in houses with large west-facing windows.

Figure 9. Shadow Length of 10-Foot Tall Object and Radiation Table for 40° North Latitude at Winter Solstice

	North Face	South Face	East Face	West Face
Horizontal				
Radiation/Day	675 BTU	675 BTU	675 BTU	675 BTU
Shadow Length	20 ft.	20 ft.	20 ft.	20 ft.
10 Percent Slope				
Radiation/Day	445 BTU	897 BTU	666 BTU	666 BTU
Shadow Length	30.9 ft.	14.8 ft.	20 ft.	20 ft.
20 Percent Slope				
Radiation/Day	224 BTU	1101 BTU	637 BTU	637 BTU
Shadow Length	73.7 ft.	11.6 ft.	20 ft.	20 ft.

Solar access planning and site analysis on steeper slopes are constrained the same as for conventional development. The steeper the slopes, the more sophisticated and expensive must site preparation be. The development of moderate south slopes is a good idea for both solar access and conventional developments.

Atmospheric Conditions

The atmosphere can also affect the availability of sunlight. For one thing, the atmosphere has a filtering effect on sunlight. The more atmosphere a given beam of sunlight has to penetrate, the less its intensity. That is another reason why the sun is less intense in the morning and afternoon. Its rays have to cut through a thick slice of the earth's atmosphere, where they can be absorbed by clouds, pollution, and the atmospheric gases themselves. The greater the distance sunlight must travel through the earth's atmosphere, the more it will be absorbed, and the less intense it will be.

Specific atmospheric conditions also take their toll of sunlight. Fog, in particular, is one condition that should be assessed. Because fog caused by cold air concentrations can significantly limit solar access, sites within a few hundred feet of each other may have very different solar potentials. This is especially true in the Pacific Fog Belt. (See figure 18.)

In areas of occasional morning fogginess, the collector can be pointed slightly west of due south, allowing the morning sun to burn off the fog and leaving the collector to gain solar radiation during the afternoon hours. (See figure 11.) In areas with severe constraints, a great deal of care must be taken to avoid fog-prone areas.

The amount of solar radiation that reaches a site is partly dependent upon the clearness of the air. Cloudiness affects a site's solar potential by obstructing direct sunlight to solar collectors. Clouds also can limit natural cooling by inhibiting the re-radiation of heat to the night sky. Finally, air quality will affect a site's solar potential. In rural areas, agricultural dust and dust clouds from quarries or other industry can lessen the sun's power. In urban areas, heavy industrial smoke, water vapor, and photochemical smog and dust can have similar effects.

Figure 10. Absorption by the Atmosphere

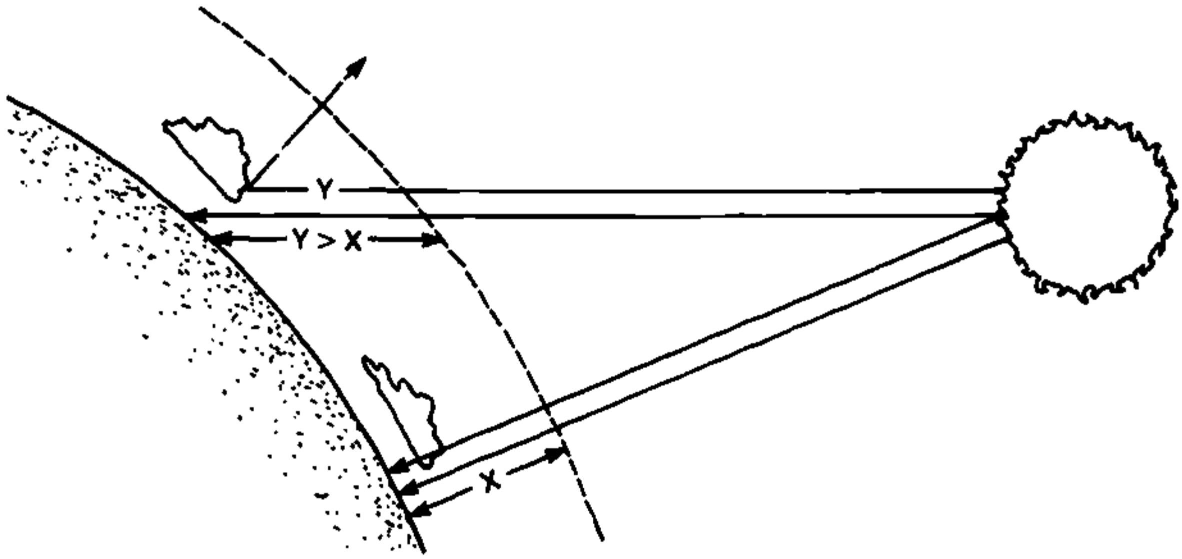
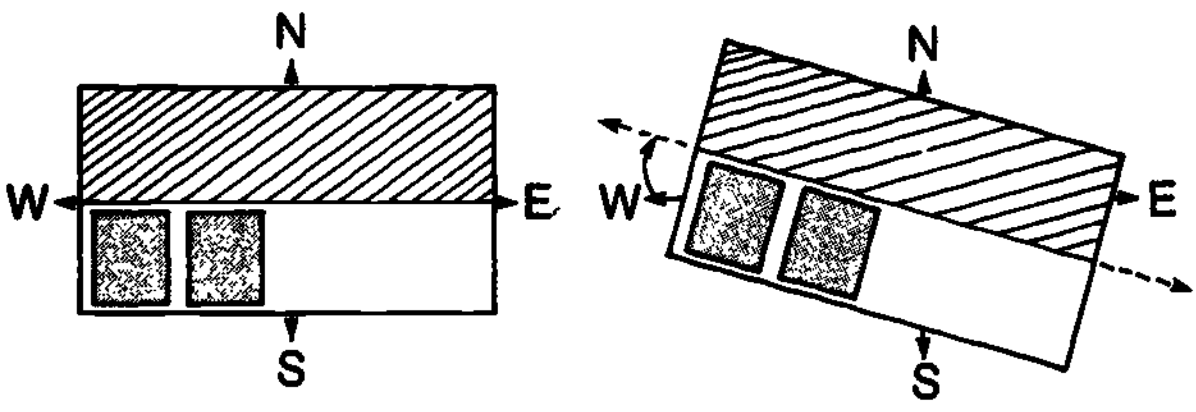


Figure 11. Orientation in Fog-Prone Areas



CLEAR LOCATION

FOGGY SITE

Severe temperature inversions also can totally change the solar access of the basins surrounding major cities. An inversion is a layer of cold air capped with a layer of warm air that inhibits vertical mixing of the atmosphere, trapping smog and haze in the lower layer. (See figure 12.) Like fogs, inversions usually have sharp boundaries. Two sites, one above the inversion belt and one below, can have entirely different solar potentials.

Assessing Shading by Natural and Man-Made Objects

A shadow cast on a solar collector affects a solar energy system's energy production in two ways. First, of course, the reduction of the amount of sunlight collected diminishes the amount of light that can be converted to heat or other forms of energy. The second loss in energy efficiency results from the radiation of heat from the shaded portion of the collector to the cooler surrounding air. Thus, it is crucial to site collectors so that they are not shaded.

Because shadows affect solar collectors, it is necessary to determine the shadow of an object near a collector. This is called the object's shadow pattern. Although a somewhat crude method, the shadow pattern enables the site planner to identify potential locational problems in siting a solar collector.

A technique for drawing shadow patterns is presented in the chapter on design approaches and in Appendix III. The developer or site planner should study this technical material in order to understand the techniques necessary for assessing shadows. At this point, however, a few generalizations can be made concerning shadows and their effects on solar access.

A shadow pattern is the composite shape of a shadow cast by an object over a given period of time. For the sake of convenience, the boundaries of the shadow pattern are defined by the sun's azimuth—two shadows, one falling 45 degrees northeast and one falling 45 degrees northwest of a north/south line running through the center of the object. This, in effect, creates a right angle

Figure 12. Inversions as Solar Access Constraints

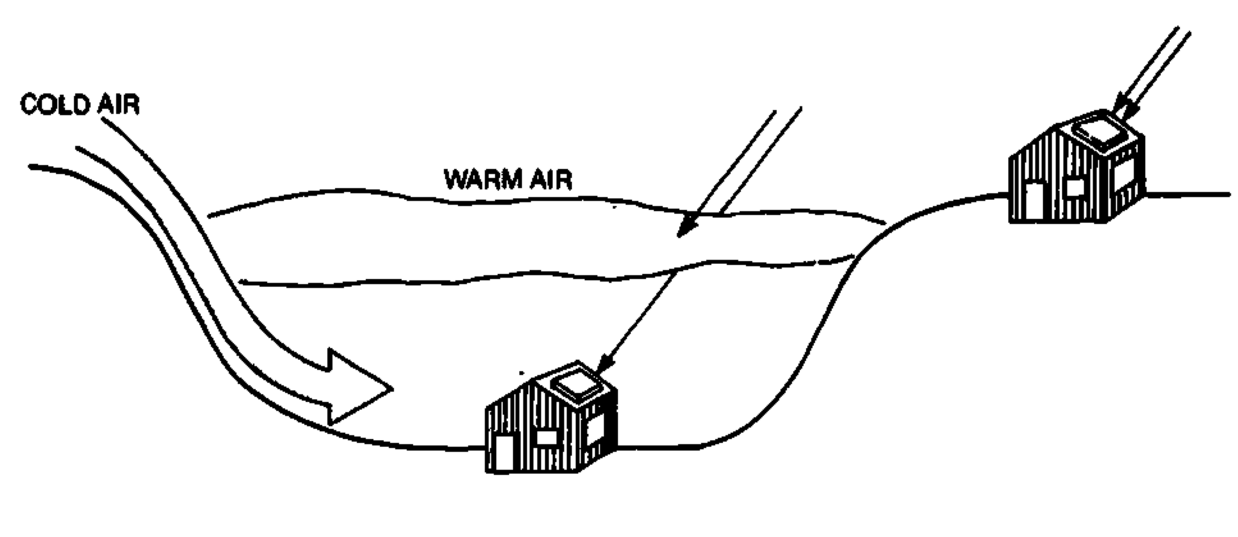
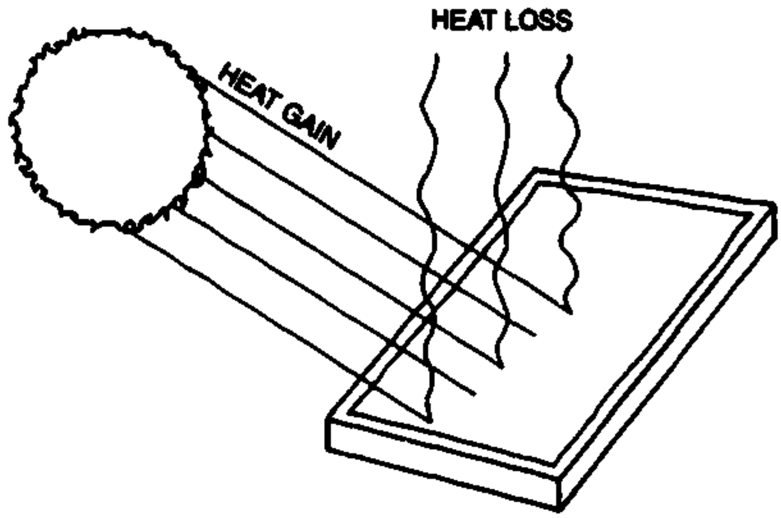
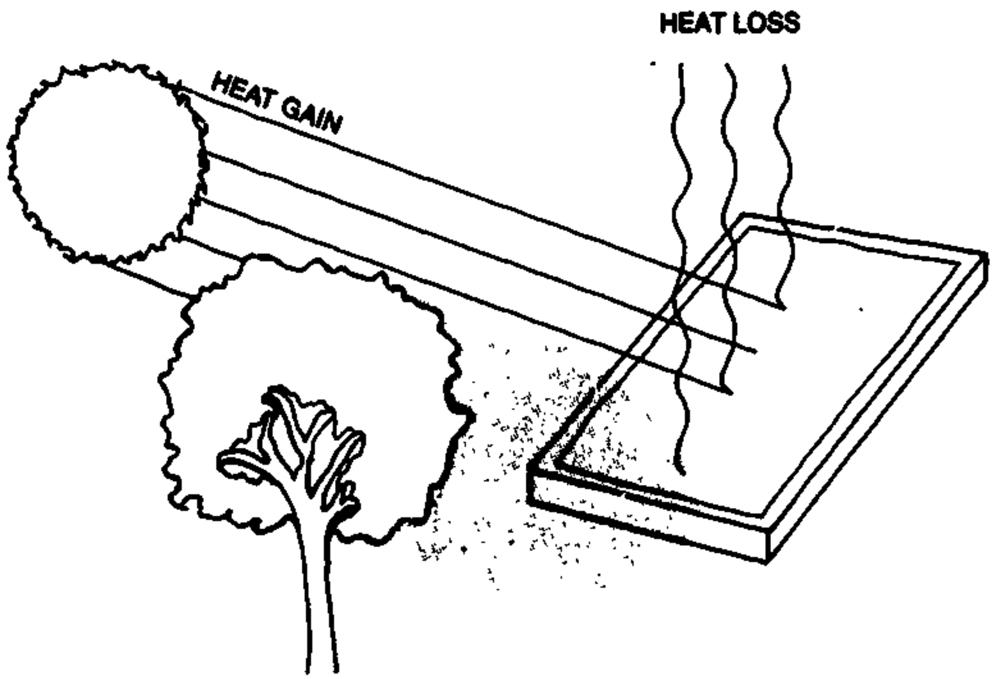


Figure 13. Collector Efficiency Loss by Shading

A SOLAR COLLECTOR GAINS HEAT FROM THE SUN AND LOSES HEAT TO THE AIR.

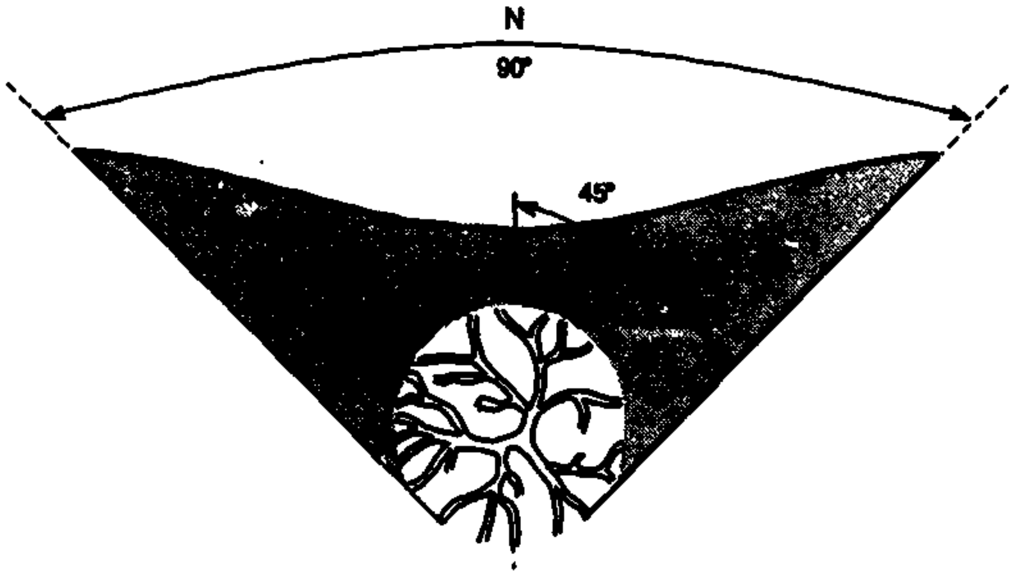


AN UNSHADED COLLECTOR GAINS MORE HEAT THAN IT LOSES

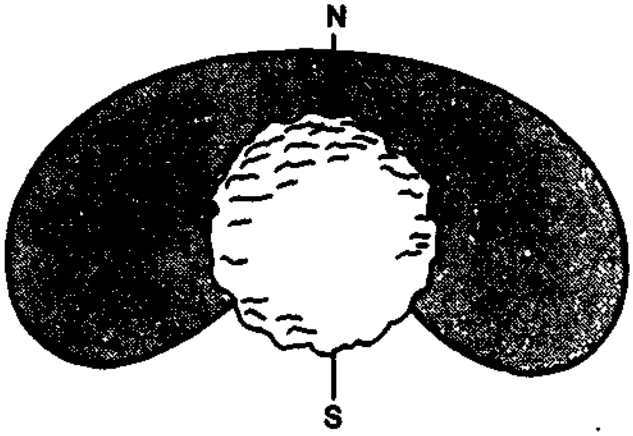


SHADING PART OF A COLLECTOR REDUCES HEAT GAIN AND LOWERS THE AMOUNT OF USABLE HEAT THE SYSTEM CAN PRODUCE

Figure 14. Winter and Summer Shadow Patterns



WINTER SHADOW PATTERN



SUMMER SHADOW PATTERN

whose sides are aimed northeast and northwest, as figure 14 shows. For most northern latitudes in mid-winter, the shadow pattern will usually be formed sometime between 8 a.m. and 4 p.m. It represents every spot shaded by the object during the entire time period needed to form the right angle, although only a portion of the shadow pattern will be shaded at any given time.

Winter shadow patterns will be longer than summer shadow patterns because the sun is lower in the sky. When planning for solar access, therefore, winter patterns are more useful; if solar access is protected for winter, then it will be protected for summer, too.

Assessing Existing Shading On A Site

Trees and buildings on or near the site must also be considered in planning for solar access. The

Figure 15. Detached Collectors Can Be Used Where There Is Excessive Shading

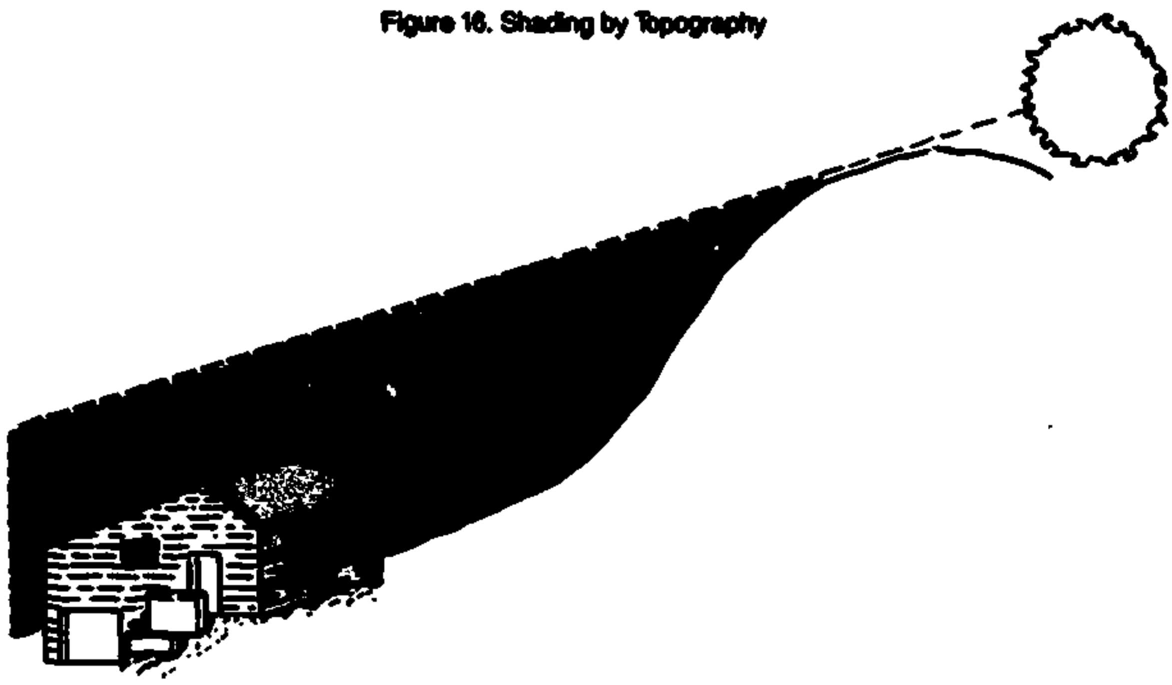
shadow patterns for objects both on and to the south of the site are calculated (using the techniques in Appendix III), and houses are located out of their way. Remember that in summer or in hot climates shading is desirable and the location of some tall trees or buildings can be used to the developer's advantage.

If trees or structures cast unwanted shadows, then the developer may have to consider alternatives, such as using detached collectors. If an off-site object casting the problem shadow is a temporary structure, abandoned, or otherwise out of use, the developer could consider negotiating with the owner for its removal.

When an adjacent site to the south is undeveloped or only partly developed, the developer may wish to protect his site against shading by future development on this adjacent parcel. A private agreement between neighboring landowners, possibly an easement, may be an appropriate response. These legal strategies are discussed in greater detail in the chapter on private agreements.

Remember, too, that hills and mountains can cause shading problems on a site. Development located close to the base of high or steep topographical features may be shaded during large portions of the day. If a project is located just to the east of a large hill, for example, it is possible that the area may be shaded relatively early in the afternoon. In order to locate the development where shading is least a problem, the developer or site planner should check to see where the shadows of topographic features fall at various times in the winter. (See figure 16.) Cross-sections of the site can be drawn and critical solar angles analyzed to determine where and what shading is likely to be a problem.

Figure 16. Shading by Topography



Assessing Energy Conservation

In addition to evaluating solar access, the site planner or developer must also consider the site's characteristics and their potential effects on overall energy use in future buildings. The microclimate of a site is an important determinant of the amount of energy that will be needed to heat and cool the buildings. Some sites are warmer in winter and cooler in summer than others. A site that moderates temperature and climatic extremes also moderates a building's heating and cooling needs, and solar collectors work more efficiently on such sites.

Besides topography, other factors should be considered. Wind flow can be affected by strategically located trees or stands of trees, which can be used to block cold winds in winter and hot dusty winds in summer. Trees can also channel

Figure 17. Vegetation Can Buffer Against Cold Winter Winds

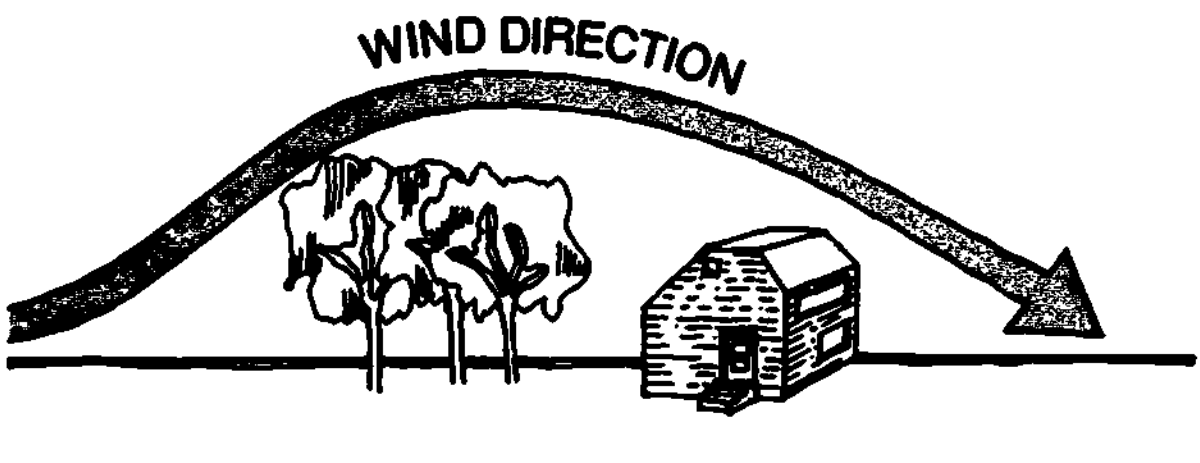
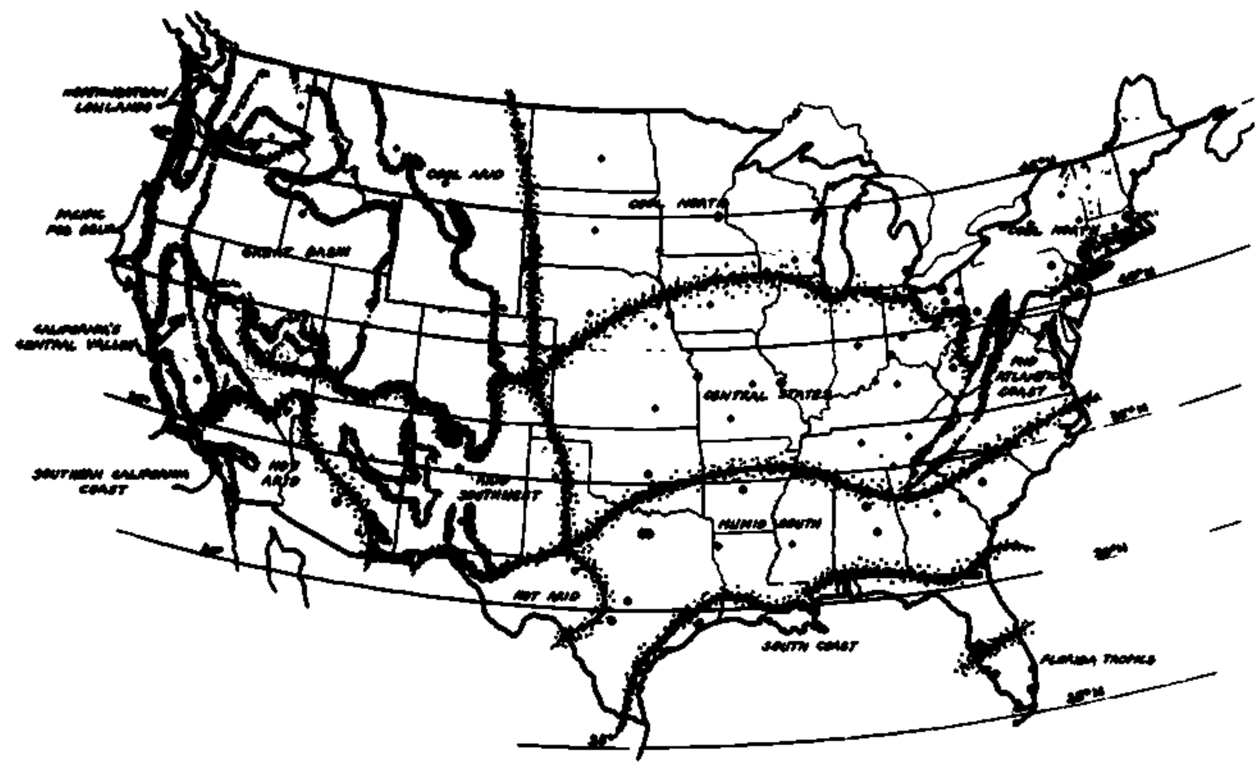


Figure 18. Regional Climate Zone Map



cooling breezes to places where they are needed, significantly lowering the heating or cooling load of a building.

The presence of large bodies of water has a moderating effect on the microclimate of a site. They also produce cooling breezes in the summer. Chicago's Lake Michigan shore area is cooler in summer and warmer in winter than inland areas. Mountains and hills can act as windbreaks and are especially advantageous when they are located in the direction of prevailing winter winds. (See reference to Olgyay and American Society of Landscape Architects in Appendix V.)

*AIA Research Corporation. *Regional Guidelines for Building Passive Energy Conserving Homes.*

Site Assessment Criteria

So far this manual has offered some general principles of site selection. But it is also possible to make more specific recommendations based on regional climatic and environmental conditions. The map in figure 18 delineates regional climatic zones for the continental United States; the site assessment criteria suggest factors to look for in evaluating sites in each zone. A word of caution: the map boundaries are only approximations, and sites that fall on or near them should be considered on a case-by-case basis.

The division of the United States into the regions shown on the map is only one approach to defining relevant regional climates. A recent publication from HUD, for example, uses slightly different climatic categories and design criteria for buildings.* Research into the use of regional climates as a design consideration has just begun and is likely to lead to further refinements.

Site Assessment Criteria

Region	Siting Guidelines			Notes
	Best	Good	Poor	
Pacific Fog Belt	Sheltered sites. Medium slopes facing southwest to southeast. Look for sites sheltered from fog and winds, both of which have regular patterns.	Flat sites with wind shelter. Shallow slopes in any direction (except northwest, northeast, and north in Oregon and Washington). On slopes over 15 percent southeast to southwest slopes will allow east/ west roads.	Windy ridges and hilltops, especially in Oregon and Washington.	Sunlight characteristics change in short distances. Make sure this is your climate. Vegetation can indicate fog and wind incidence. For example, redwoods indicate fog; sheared cypress and bay indicate wind.
Northwestern Lowlands	Midway up southwest to southeast slopes, sheltered by trees and topography.	Southerly slopes, flat sites with good solar access and gentle east and west slopes.	Northwest to northeast slopes, frost hollows, exposed ridges, steep west slopes.	Beware of sites with evergreen tree cover: they limit solar access.
Great Basin/ Cold Arid	Sites on lower, sheltered south to southeast slopes 5 to 15 percent.	Sites with south orientation and wind shelter.	North slopes, cold air drainage, and exposed ridges.	
Arid Southwest/ California's Central Valley	Lower south and southeast slopes for early cool-season warmth.	Upper south and southeast slopes; flat land.	North slopes (difficult solar access) and west slopes (afternoon overheating problems).	
Southern California Coast	Any south-facing site on moderate slopes.	Any south-facing site on moderate slopes.	Avoid only steep slopes to north, northeast, and northwest; on more inland sites avoid steep east or west slopes.	This is the least exacting of any U.S. climate. Determine whether site is in a summer fog belt or in the summer inversion layer.
Hot Arid	South to southeast slopes, flat land, shallow north slopes.	Flat land, cool air drainages, cool ridges.	Southwest/northwest slopes, steep north slopes, hot valley bottoms.	Sites near water tend to be cooler.
Cool North	Sheltered sides on gently south-facing slopes.	Sheltered sites on flat ground or any slope southeast to southwest.	Exposed ridges, hillcrests, north slopes, steep west slopes, frost hollows, windy sites.	South orientation and wind shelter are the keys.
Central U.S.A./ Mid-Atlantic Coast	Gentle southeast to southwest slopes with scattered, mature trees.	Flat sites, wooded sites, sheltered slopes, steep slopes south to southeast.	Windy ridges, steep north, northwest, or west slopes, unventilated depression.	Look for winter sun and wind shelter, summer shade and breezes.

Site Assessment Criteria

Region	Siting Guidelines			Notes
	Best	Good	Poor	
Humid South	Mature deciduous woodland on gentle south or north slopes.	Mature deciduous woodland on gentle slope in any direction; flat sites; scattered trees on steeper north or south slope; breezy ridges.	Sites without breezes; steep slopes; treeless sites.	Look for a balance of sun and shade, good summer breezes, and mature deciduous trees.
South Coast	Mature deciduous woodland on flat land or gentle slopes. Ridgetops with good breezes.	Mature deciduous woodland on steeper north, east, or west slopes.	Steep or sheltered slopes any direction, unventilated pockets, treeless sites.	Mature trees and air movement are the keys to cooling here.
Florida Tropics	Mature broadleaf woodland essential, ridgetops, north slopes, gentle south slopes.	Mature broadleaf trees on flat sites.	Treeless sites, steep east and west slopes, airless hollows without breezes.	Through breezes and mature shade trees are more important than solar access.

Preliminary Site Planning

Once a site has been examined for access to sunlight, shading problems, and energy-conserving features, the developer or site planner can begin preliminary site planning. This chapter discusses preliminary site planning as a three-step process: first, solar access goals are adopted; then, local regulations are assessed; finally, a base map of the site showing constraints and opportunities is developed.

Considering Solar Access Objectives

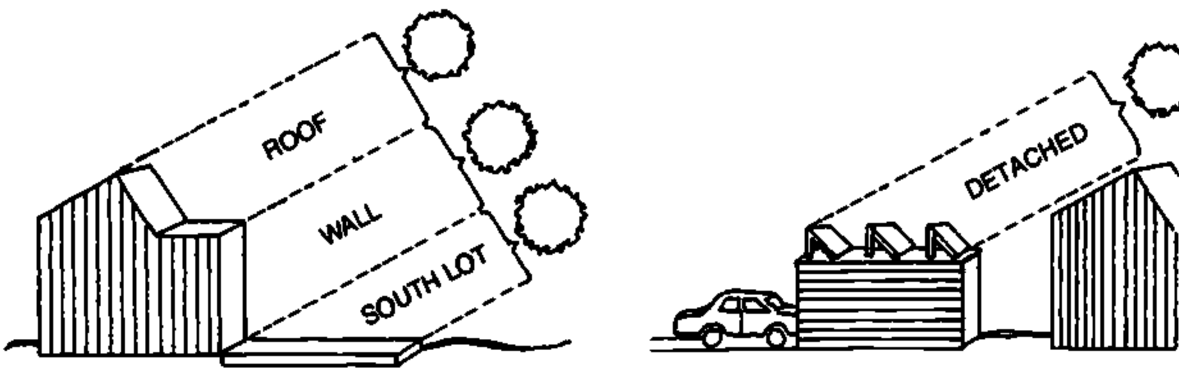
The developer's first task in preliminary site planning is to consider the optimum amount of solar access for the development. In protecting the availability of sunlight to solar collectors, the developer must consider where the solar collectors may be located and how much area around them must be kept free of obstructions.

Levels of Solar Access

The collector locations for active and passive heating systems fall into four categories: rooftop, south wall, south lot, and detached. (See figure 19.)

Rooftop access may be the best alternative for high-density developments or sites where topography or high northern latitudes make south-wall access difficult or impossible. This level of access may involve the least number of design considerations, especially if buildings in the development are all of the same height and not likely to shade one another. For these situations, site planning focuses on possible shading from trees or tall buildings in neighboring developments. Rooftop access may be most appropriate for solar hot water heating and active space heating collectors.

Figure 19. Levels of Solar Access



South-wall access is recommended for almost every development situation, simply because it leaves open the possibility of using either active or passive solar energy systems. South-wall access is particularly appropriate where a developer is merely subdividing and not necessarily building a development. It preserves a variety of solar options for future lot owners. South-wall access can also be important when using roof-mounted collectors, because south glazing can assist the solar energy system in space heating.

South-lot access is more difficult to achieve than either roof or south-wall access. It may require greater care in the siting of buildings and trees to minimize shading problems. Some climates permit the use of a reflector to increase sunlight falling on a collector, and south-lot access may be necessary for the proper placement of the reflector. Where a light-colored or snow-covered patio is used as a reflector to increase radiation to the collector, these features should be considered by the site planner or developer. Similarly, the use of a solarium or solar greenhouse could require that south-lot access be considered a solar access objective. Finally, south-lot access is also desirable in regions where residents make extensive use of yards and patios; south-lot access can provide a warm, sheltered location for outdoor activities.

Detached collector access can be considered in situations where rooftop mounting of collectors is not possible or desirable. For example, in heavily wooded areas whe e the vegetation must be preserved, or in hot climates where maximum shade is desirable, detached active collectors offer a good compromise. Detached access may be necessary for those sites with predetermined plots and/or street layouts that have precluded good solar access. In warmer climates, where space heating may not be necessary but where solar water heating is important, the house can be shaded by nearby trees or sunscreens to reduce the need for air conditioning, and a detached collector can be used. Detached collector arrays can be mounted in a variety of locations and can be integrated with other site uses, such as open space or accessory buildings.

The developer or site planner may also wish to consider the effects of solar access on the cooling needs of new residential development, particularly in those regions where most residential energy is used for air conditioning. *Active solar cooling systems* have virtually the same access needs as active solar heating systems. High-temperature solar collectors require direct access to sunlight in order to work properly. *Passive or natural cooling systems* have fewer access requirements than passive heating systems. Clear access to the cool sky or unobstructed access to cooling winds is all that is necessary. Maximum shading of buildings using passive cooling (to reduce heat loads) is more important than solar access in hot climates.

In most cases, a developer need only decide between active or passive solar energy systems before being able to determine the necessary level of solar access. Generally, the more solar access provided, the greater the need for careful site planning considerations. As access changes from roof access to south-wall access to south-lot access, the placement of trees and structures becomes more crucial to prevent shading of these areas.

Solar Skyspace

Once a developer has determined the level of solar access for the project, the individual unit of solar access, called solar skyspace, must be considered. Solar skyspace is that portion of the sky which must remain unobstructed for a collector to operate efficiently; in other words, the area to the south of the collector that must be kept free of obstructions when the collector is in use. Solar skyspace for most solar heating systems is determined by the sun's position at the winter solstice (December 21), when solar altitude and azimuth angles are smallest and shadows are largest.

As a rule-of-thumb, 12 degrees altitude can be used as a cutoff point for solar skyspace. Roughly 80 percent of the sun's energy is received when the sun is at or above 12 degrees altitude as illustrated in figure 20. The sun is in this position between 8 a.m. and 4 p.m. for most latitudes at mid-winter. This altitude corresponds to 45 to 50 degrees azimuth either side of south, forming a 90 or 100 degree wedge; a line bisecting this wedge would point north/south. In most of the United States, below 45 degrees north latitude, 45 degree azimuths are used to define skyspace. These limits are expressed in azimuths because clock time is often significantly different from solar time.

Thus, the *eastern and western boundaries* of the skyspace may be defined by 45-degree azimuth angles. The altitude of the sun on December 21 and June 21 determines the *upper and lower boundaries* of the skyspace in most cases. Figure 22 shows in two different views how the winter and summer paths of the sun connect with the east/west boundaries to define the skyspace area.

The upper and lower skyspace boundaries also depend on the type of system to be used. For in-

Figure 20. A 12°-Solar Altitude is Necessary to Define Solar Skyspace for Active Collectors

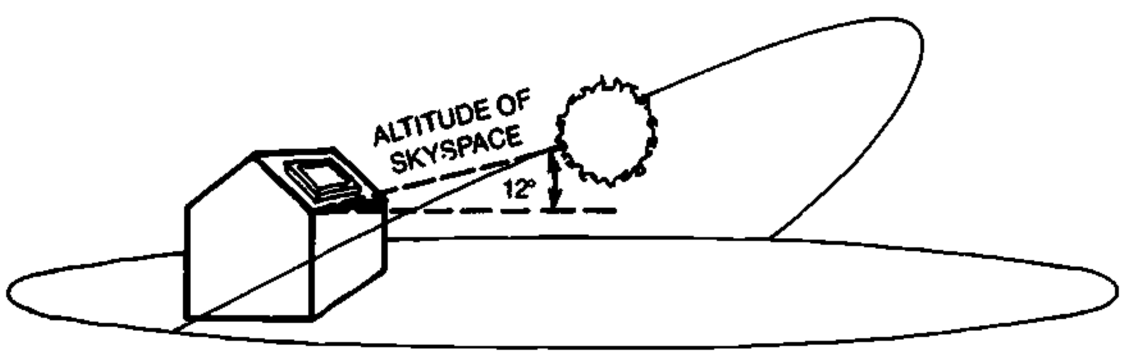


Figure 21. Solar Skyspace (Plan View)

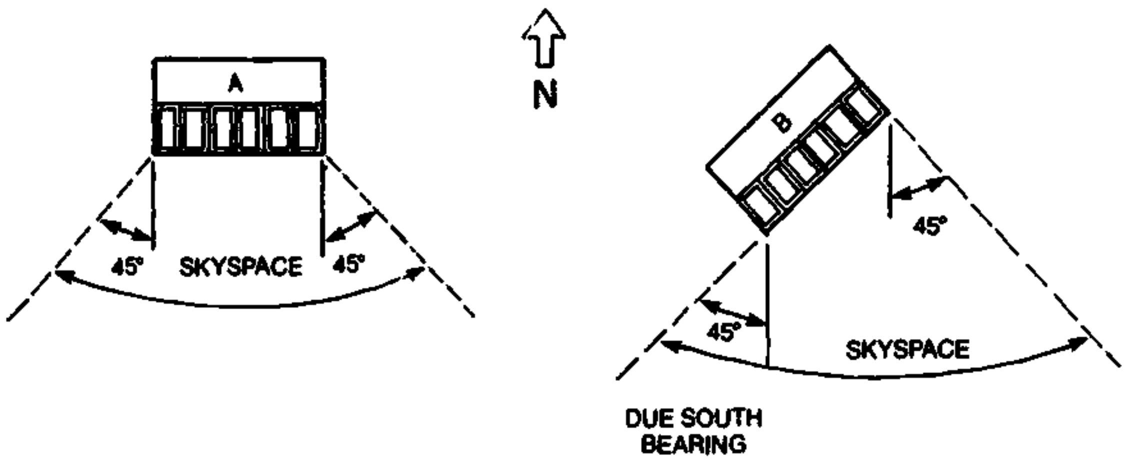


Figure 22. Solar Skyspace (Plan and Isometric Views)

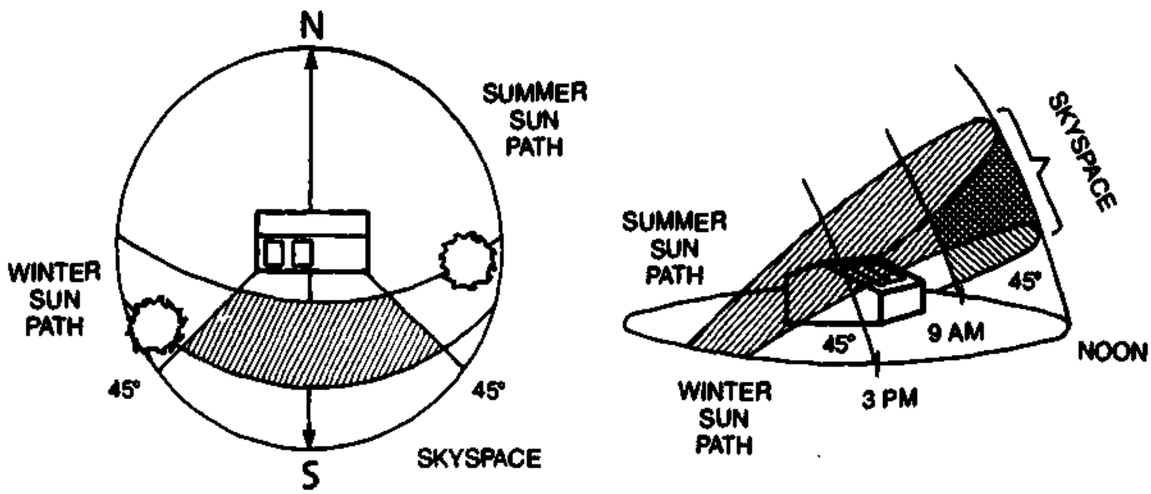


Figure 23. Recommended Skyspace Angles for December 21

N. Latitude	AM/PM Position* Azimuth	AM/PM Position* Altitude	Noon Altitude	Percent Radiation***
25°	45°	25°	42°	76%
30°	45°	20°	37°	80%
35°	45°	16°	32°	85%
40°	45°	12°	27°	90%
45°**	(50°)	(12°)	22°	88%
48°**	(50°)	(12°)	18°	87%

*The AM/PM angles presented in this chart are the same for both east of south and west of south. For example, if the skyspace azimuth is 50°, then the protected area goes from 50° east of south to 50° west of south.

**The 50° azimuths are not based on December 21st, but are suggested as a compromise to assure solar access during the entire heating season exclusive of the winter solstice period. Similarly, the 12 degree altitudes apply only to those months when the sun's path is 12 degrees above the horizon within the 50 degree azimuth angles. See Appendix II.

***Radiation is based on the percentage of total available radiation falling on a horizontal surface on December 21. Example: If the skyspace between 45° east of south and 45° west of south is protected at 30° latitude, then 80% of the available radiation will strike the collector. If the collector is tilted, then these percentages may be even higher.

stance, a hot water system needs year-round access, so the lowest winter sun angle and highest summer sun angle are used in defining skyspace. A space heating system used only in winter can operate efficiently with a lower skyspace boundary. (See figure 24.)

In either case, the upper boundary is not as important as the lower. The lower boundary is formed by the sun's path at its lowest point; on December 21 the problem with shadows will be most difficult, because that is when the shadows are longest. Only for passive cooling systems, which radiate heat to the cool night sky and need an open space directly overhead in the summer, is this consideration irrelevant.

In summary, solar skyspace for heating purposes is defined by the path of the sun on December 21 between 45 degrees east and west of south. In planning a development, large objects capable of casting significant shadows should be located so that they do not intrude into the skyspace wedge or extend above the lower boundary. Figure 25 shows three solar energy uses and describes how the season during which each is used affects solar skyspace. (Skyspace is discussed further in Appendix I.)

By combining the level of solar access with the solar skyspace, the developer can determine exactly what area must be kept free of obstructions. If rooftop access is the goal, for example, the individual skyspace unit begins at the building eaves (as figure 26 shows); if south-wall access is chosen, then the skyspace begins at the bottom of the south wall.

Figure 24. Skyspace Boundaries for Water and Space Heating

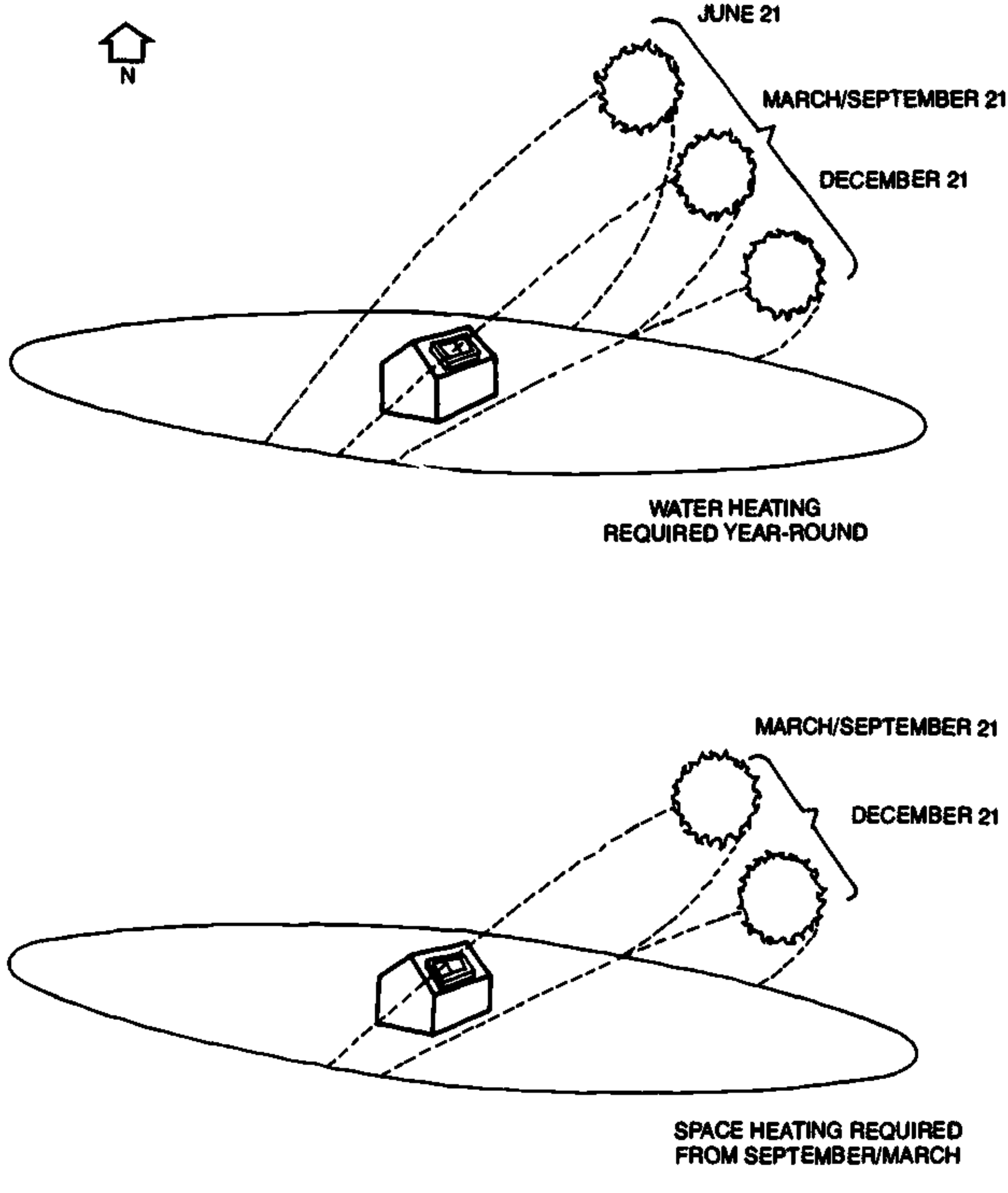
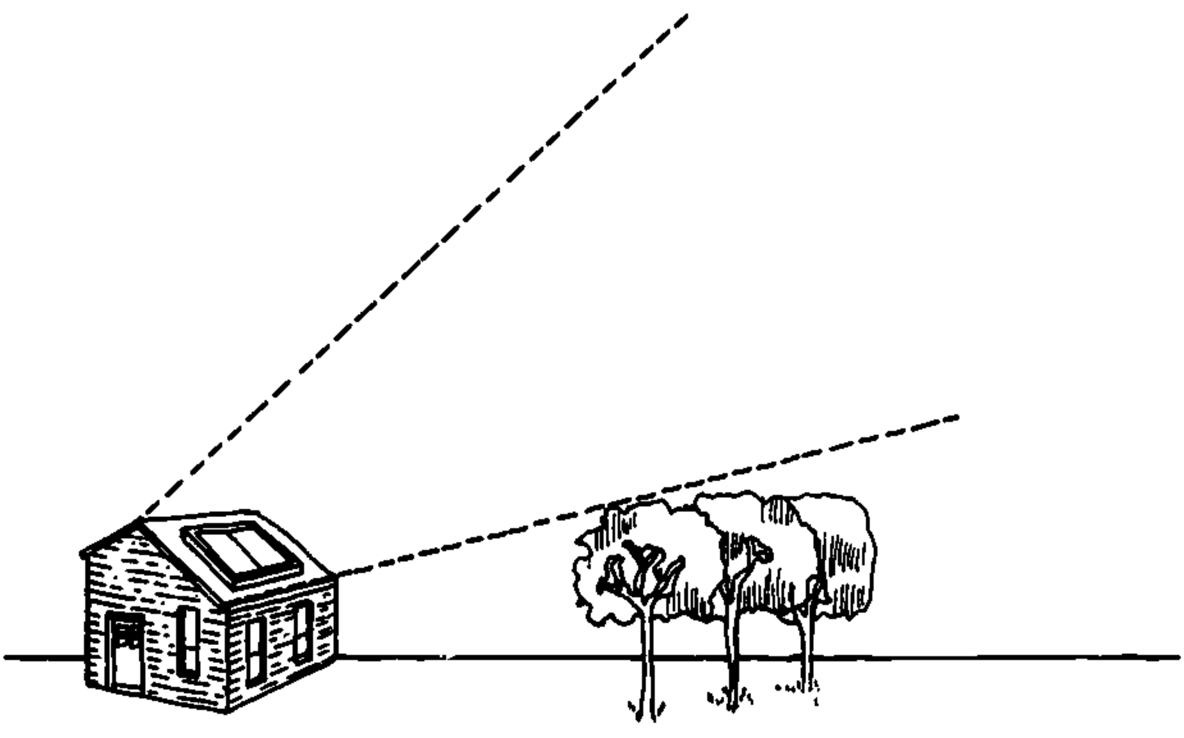


Figure 25. Skyspace and Solar Energy Use Table

Use	Skyspace
Water Heating	Year-round—use lowest winter and highest summer altitude to determine skyspace
Space Heating	Heating season only—use lowest winter and medium spring/fall altitude to determine skyspace
Air Conditioning	Cooling season only—use medium spring/fall and highest summer altitude to determine skyspace

Figure 26. Skyspace Begins at the Roof Eaves for Rooftop Access



Topography and Solar Skyspace

Changes in topography do not change solar skyspace. An unobstructed area is necessary on a slope facing any direction. What does change is the distance between the ground and the lower edge of the skyspace. A south slope automatically "aims" its collector higher, so neighboring objects can be tall without casting shadows on it. A collector on a north slope will be aimed toward the crest of a hill, so even very short objects may cast shadow onto the collector. Figure 27 illustrates this point.

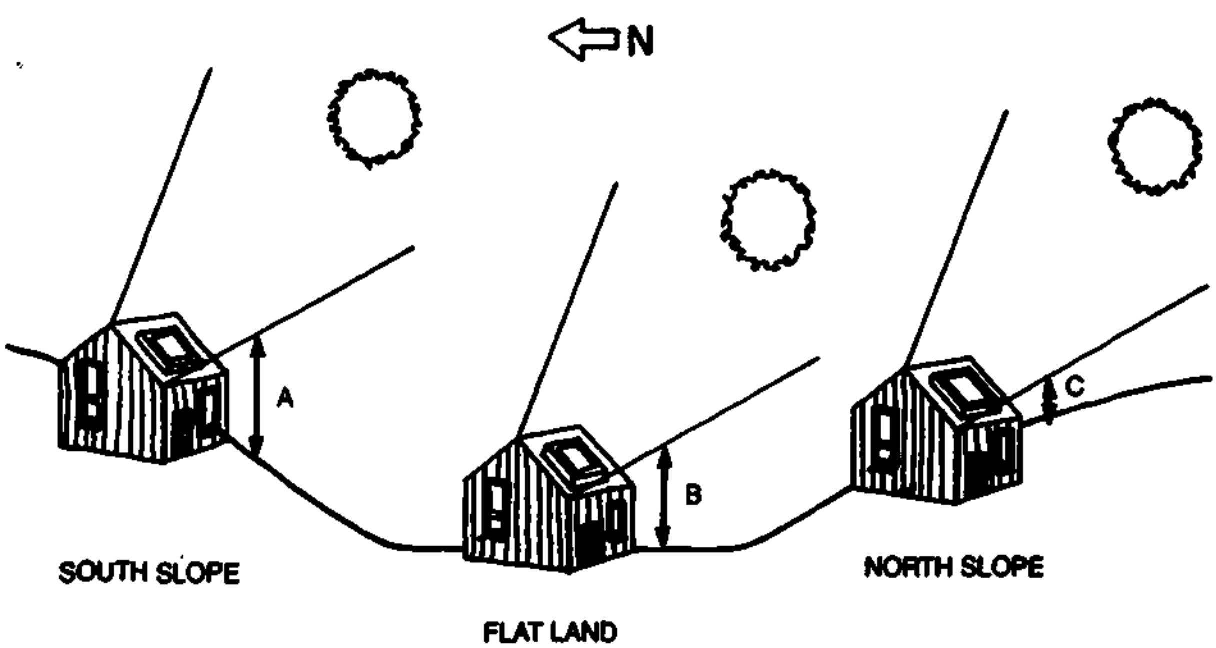
Slopes can affect the developer's design strategies. On a south slope, for example, it is possible to put in higher densities of housing with unobstructed solar access than on north slopes. Similarly, solar access may be limited on steep north slopes unless density or layout is changed to account for the lower solar skyspace over adjacent lots.

Assessing Local Regulations

Land-use controls establish development objectives—the density, the number and kinds of structures allowed within the development, the requirements for infrastructure (such as sewers, electric lines, and water), and for public amenities (such as open space). To be approved by the community a development proposal must meet these standards.

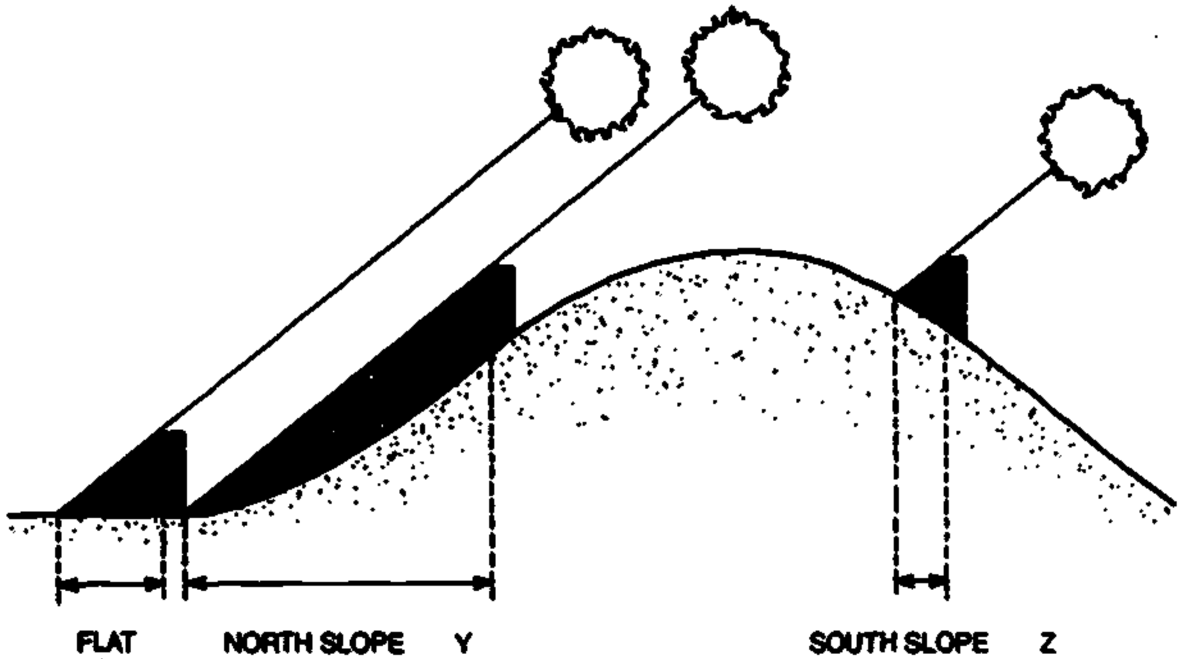
But it may be unclear to what extent local regulations offer opportunities or barriers to developments planned for solar access. Actually, it depends largely on the type of development and the land-use controls in effect in the community. A community, for example, may have highly restrictive zoning standards governing new development, standards that rule out solar equipment. Another, however, may have flexible development regulations, such as planned unit development (PUD) provisions that offer developers a great

Figure 27. Topography and Skyspace



DISTANCE A IS GREATER THAN B. AND B IS GREATER THAN C.

Figure 28. Shadow Lengths Are Shorter and Higher Densities Easier on South Slopes



DISTANCE "X" ON A FLAT SLOPE IS LESS THAN DISTANCE "Y" ON A NORTH SLOPE, FOR IDENTICAL POLES. DISTANCE "Z" ON A SOUTH SLOPE IS THE LEAST.

deal of flexibility in building placement and design, including solar access concerns.

A developer considering a solar development or a project planned for solar access must also consider potential barriers presented by local land-use controls. Discussed extensively in the companion guidebook by the American Planning Association, *Protecting Solar Access for Residential Development,* these concerns are surveyed below.

Barriers in Regulations to the Use of Solar Energy

Developers will find that in some communities zoning ordinances will contain provisions that technically could prohibit the use of solar energy systems.

First, zoning height restrictions could prevent the use of rooftop collectors or other rooftop apparatus used in solar energy systems. Usually, zoning provisions that limit height make exceptions for antennae, chimneys, and similar ancillary structures. Adding solar collectors to such a list of exempted structures would permit the use of rooftop apparatus.

Second, restrictions on projections into side yards could prohibit the use of overhangs or other structures used in passive solar energy systems. Some systems require large overhangs or moveable roof covers that partly cover the yard at certain times. In most cases, certain projections, such as fire escapes or overhanging eaves, are exempted from these restrictions. As in the case of height restrictions, it may be necessary to modify the overhang restrictions to permit the use of shading devices.

Third, maximum coverage restrictions could prohibit the use of ground-mounted collectors. Terraces, balconies, and porches are not included in computing lot coverage; the same policy could be made for solar collectors. Since it is not desirable for an entire lot to be covered with solar collectors, however, some limited restrictions might be placed on the use of detached collectors to prevent this.

Developers will undoubtedly face other zoning restrictions and other kinds of regulations (such as street tree ordinances) in their attempt to use solar energy systems. It is the developer's responsibility to show public officials that the community will benefit if these provisions are flexible enough to permit reasonable solar development. The companion regulatory guidebook can be useful in this respect.

Solar Access, Density, and Environmental Protection

Local regulations establish development goals for both the community and the developer. It is likely that once barriers to the use or installation of solar energy equipment are identified and eliminated, conflicts between solar access needs and local development standards will diminish. In most cases, good solar access site planning (i.e. planning that takes into account environmental factors affecting the availability of sunlight as well as energy conservation) will surpass the minimum development standards set forth in local regulations. The result will be a unique, innovative, well-planned development that is an asset to the community.

Designing a development for solar access does not have to conflict with conventional development standards. Density, energy conservation, environmental protection, landscaping, and other objectives can be accommodated easily while planning to promote solar access.

Density concerns need not rule out solar access planning. Depending on latitude and topographic conditions, it is likely that full buildout, as authorized in local regulations, can be maintained while solar access is still protected. For example, the recent study of a development indicates that densities of over eight dwelling units per acre are possible even in latitudes as far north as New York City, provided that streets are oriented east and west.* If townhouse or multifamily development is proposed, then densities can go even higher without sacrificing south-wall access. Relatively high densities for single-family developments are also illustrated by the examples of solar access developments in the chapter on solar site planning; where densities of over seven dwelling units an acre are easily achievable for both conventional and PUD development at 37 degrees north latitude.

Density becomes a crucial issue when the site has rolling topography and relatively steep slopes. The density examples discussed above apply to flat or level sites, but density objectives can change dramatically, depending on slope gradient and direction. For example, higher densities may be possible on south-facing slopes because shadow lengths are shorter. Conversely, north-facing slopes, especially steep ones, may require reduced densities if solar access is to be protected. In PUDs, these differences in density can be balanced off—south slopes on a site can be designed with densities higher than those authorized, while north slopes can be more sparsely developed. In areas with poor solar access potential, solar access goals may have to be modified to achieve other development objectives—south-wall access, for example, may be infeasible, leaving roof access as the next desirable objective. Techniques for determining density are discussed in greater detail in Appendix IV.

Environmental protection is also compatible with solar access protection. Although solar energy use is not so closely tied to environmental goals as energy conservation, the design options described in this guidebook need not conflict with practices for controlling runoff, open space preservation, and related conservation practices. When it is necessary for streets to follow topography, it is still possible to site lots and buildings for proper solar orientation and access. With good site planning, areas restricted from development can be dedicated for open space, and this open space can facilitate both the environmental objective and solar access protection.

Another environmental concern involves protecting steep slopes from development. Although south slopes are particularly desirable from a solar access standpoint, soil conditions or the severity of the slope may entirely restrict or preclude development. As in conventional development, building on such slopes, when permitted at all, is likely to be difficult and expensive.

Meeting landscape standards may require compromise. Protecting solar access will sometimes mean selectively removing trees, especially in forested areas—not clearcutting, but selective removal to the south of buildings. Heavily forested sites probably should not be developed for solar energy use. This is discussed in greater detail in Trees and Landscaping.

*Testimony of Richard Stein, *A Forum on Solar Access*, pp. 19-20.

Creative planning and design can accommodate these and other environmental restrictions both imaginatively and economically.

Conventional Versus Planned Unit Development

Local ordinances often give the developer a choice. He can follow prescriptive regulations that establish minimum building or development standards, such as those in conventional zoning and subdivision ordinances. Or, he may choose the planned unit development (PUD) option, which enables him to negotiate with the community in designing a project and developing a parcel of land. The PUD approach offers greater flexibility at the cost of increased pre-planning effort and negotiation time. Sometimes PUD ordinances contain incentives, such as density bonuses, to encourage innovative site design or to secure amenities for the community.

The development strategy and the selection of particular ordinance provisions that allow increased design flexibility are important considerations in planning developments for solar access protection. In assessing the options discussed in this chapter, the developer also should determine whether a specific approach is more suitable under conventional or under PUD provisions. Where conventional zoning standards are sufficiently flexible, this may not be an issue. But, when local regulations are fairly specific in their building spacing or other requirements, the developer may be better off with a PUD approach.

Many solar developments were actually built as PUDs, because the communities in question had not modified their regulations to accommodate solar energy use or solar access protection. Consequently, developers interested in protecting solar access had no choice but to proceed under the PUD approach. Incidentally, many developers who have built or designed solar developments have reported few problems in negotiating with local officials about development review and approval.*

Site Planning Criteria and Procedures

Establishing site planning criteria typically involves answering such questions as:

Which varieties and types of housing are desired?

What contribution will solar energy and natural cooling make to the development's overall energy use?

What use(s) other than housing must the site include?

What special relationship among buildings and between buildings and topography are required?

What existing features of the site, both natural and man-made, need preserving?

What vehicular access is required?

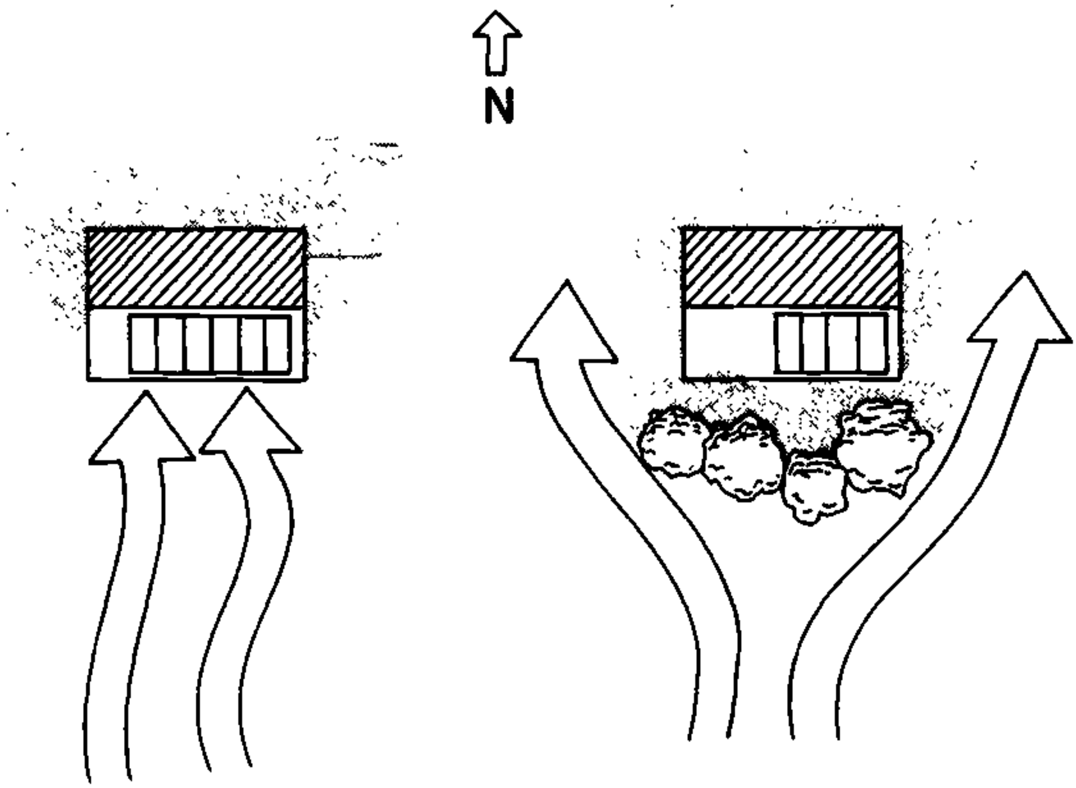
Many of these development decisions are already established by local regulations. For example, the site might be in a zoning district that allows only single-family, detached housing. To achieve other goals, the developer may have to petition for a rezoning or use optional PUD provisions—both of which require negotiation, increased development risk, and possibly more time and cost. Other considerations include drainage, road standards, and open space requirements.

The preliminary layout of land uses on a site can follow two approaches. The developer can achieve development objectives by a preliminary layout that ignores the identified opportunities and constraints indicated in the base map, in the hope of overcoming these limitations by technical design. Alternatively, the developer can base the preliminary design of the project on the opportunities and constraints shown by the preliminary site assessment. This second approach is recommended in this manual, even though the solar access site analysis may increase front-end planning and development costs over those anticipated for conventional development.

Because of the nature of solar energy technology, solar access site planning requires careful preplanning. If a conventional structure is poorly planned for energy conservation, the error can be partly offset by installing a larger furnace. Sometimes increasing the size or efficiency of the collector or modifying the design of the house to conserve more energy can compensate for poor collector siting. Such structural modifications include triple-glazing windows, berming or creating partly underground homes, and installing windbreaks. But then the benefits of using solar heat are negated, and the building must rely more on conventional heating sources (but

*Real Estate Research Corporation, *Working Papers on Marketing and Market Acceptance.*

Figure 29. Wind Buffers Can Reduce Collector Area



less so than if the building were not solar tempered). The heat from a solar collector is low grade when compared to the heat generated by a furnace. A solar collector is most efficient when it is well integrated with the natural features of the site. (See figure 29.)

The most cost- and energy-efficient use of solar energy can be calculated by using certain computer models, such as HUD's RSVP (Residential Solar Viability Program) or the Department of Energy's SOLCOST program. Information about these programs is available from the National Solar Heating and Cooling Information Center, which also offers guidance in choosing the optimum collector size for a specific dwelling. The economics of solar use are beyond site planning. As in conventional environmental site planning, careful site planning merely shifts costs to an earlier stage in the development process. They are recouped in lower construction costs and do not increase total project costs.

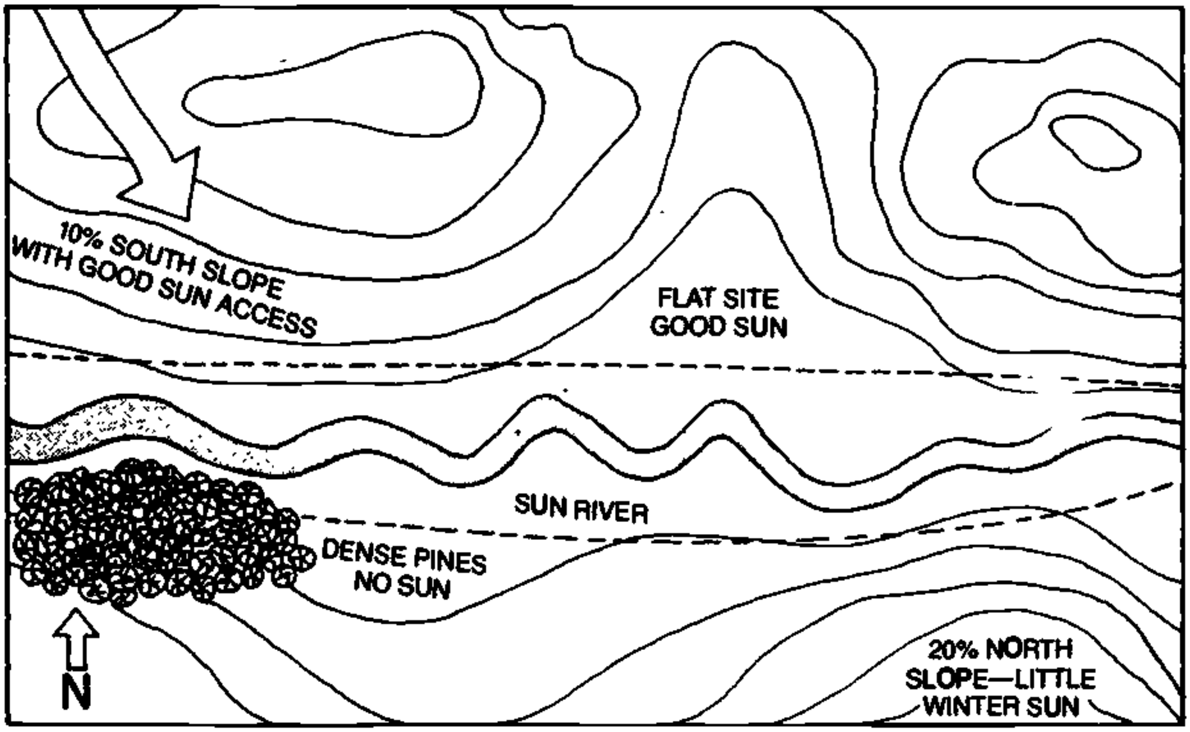
Preliminary Site Planning Procedures

Based on the analysis of the site, the developer or site planner can proceed to allocate the major land uses of the project, including housing, open space, and transportation. In practice, site analysis and preliminary site planning are accomplished more or less simultaneously but are presented separately here for simplification.

Assessing a site for solar access and energy conservation is only a part of preliminary site planning. Developers must also decide which areas of a site are more desirable for building from an environmental standpoint. Some areas, for example, have more stable soils than others. The goal is to identify suitable areas for buildings, open space, streets, and other components of the project.

In analyzing the site, solar access and energy-conserving features of the site should be identified and mapped on a base map. The base map should be an aerial photograph of the site, a

Figure 30. Base Maps Should Be Analyzed for Solar Access



topographic map, or a land feature sketch. (See figure 30.) The site can then be evaluated according to the site analysis checklist.

Site Analysis Checklist

1. *Map topographic and major site features.*

   Indicate slopes and flat areas.

   Indicate existing trees and buildings.

   Mark site elevations and contours.

   Mark all significant natural features, such as water courses or historic sites.

2. *Map all potential solar access obstructions.*

   Indicate individual trees, noting species, height, and whether evergreen or deciduous.

   Indicate all tall objects on the site or on adjoining property that can cast shadows on the site; estimate location and height.

   Indicate all north slopes or other areas with poor solar access, such as fog pockets.

   Sketch shadow patterns of major tall obstructions on the plan.

3. *Map all energy-conserving factors of the site.*

   Indicate seasonal wind directions and features that can influence wind flows.

   Mark possible frost or fog pockets.

   Note bodies of water.

   Note air quality.

   Indicate ground surfaces, such as bare soil, pavement, grass. Note reflective surfaces such as sand, water, concrete.

4. *Discuss the terrain and site limitations* with neighbors and other people familiar with the area.

A Solar Site Planning Example

How would the principles and techniques described be used in actual practice? Let's take a hypothetical case to see how it is done.

First, the development objectives established in local zoning and subdivision regulations are compared to the base map developed as part of the site analysis. The easiest method for assessing these objectives and comparing them to both solar energy use and site constraints is to use overlay maps. Information is mapped on the overlays and placed over the base map and bubble diagram map to determine the suitability or unsuitability of site areas.*

The first overlay should clearly show site constraints that prohibit the economic development or that threaten the environmental resources of the site. This overlay can be labeled "Exclusions," as in figure 31. Excluded areas can be considered for other uses that are consistent with the development objectives.

*A good discussion of this technique for environmental site planning is discussed in the Planning Advisory Service's *Caring for the Land*.

Next, the solar access potential of the site should be mapped on an overlay and placed over the base map. The overlay should also suggest the solar energy objectives within the development, the constraints indicated by the site analysis checklist, and the regional building climate criteria. This map should be overlaid on the exclusion map and base map to indicate areas of optimal development potential and solar access, as in figure 32.

The site should then be examined for energy-conserving site features, such as sheltered areas or trees that dam cold wind flows down slopes. Poor energy-conserving features should be identified on the base map, including exposed ridges or frost-prone areas at the foot of north-facing slopes. These frost pockets require greater care in building siting and may require larger collector areas to compensate for heat loss. (See figure 33.)

Figure 31. Site Exclusions Marked on the Base Map

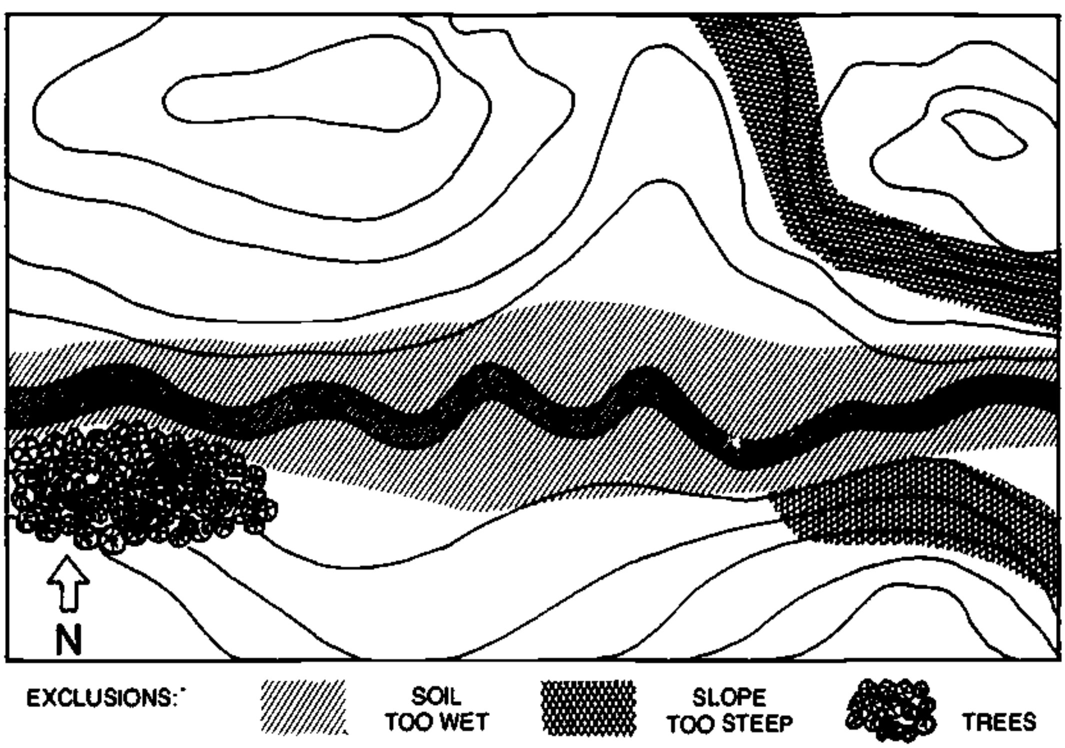


Figure 32. Areas of Poor Solar Access Should Be Marked on the Base Map

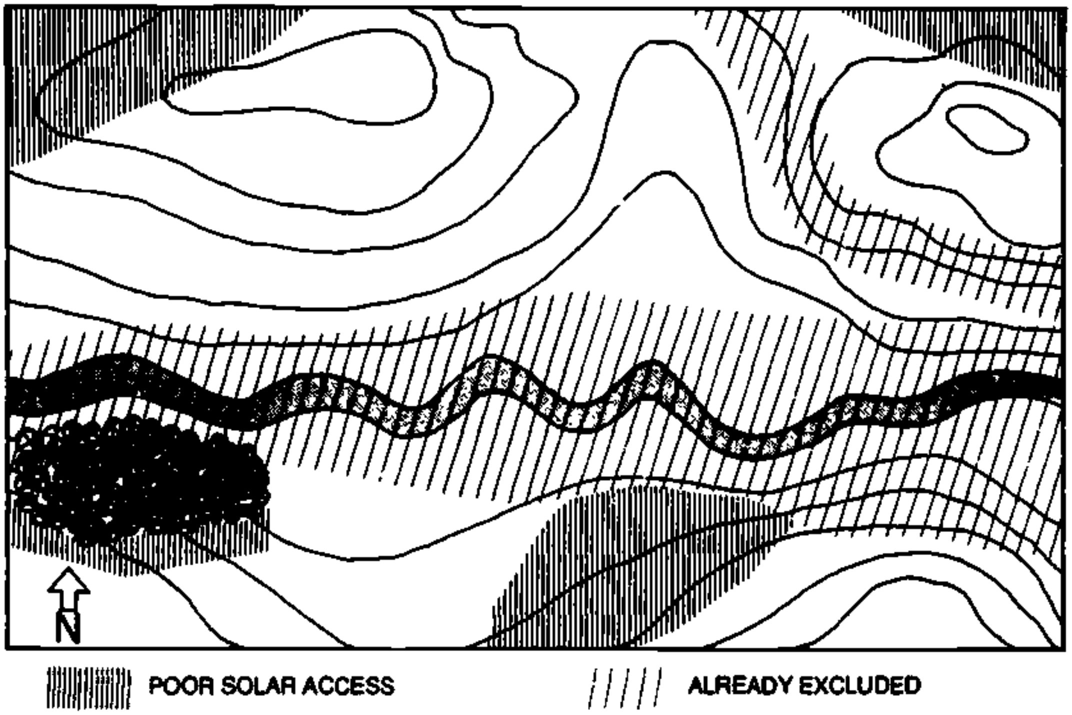


Figure 33. Areas with Poor Energy-Conservation Features

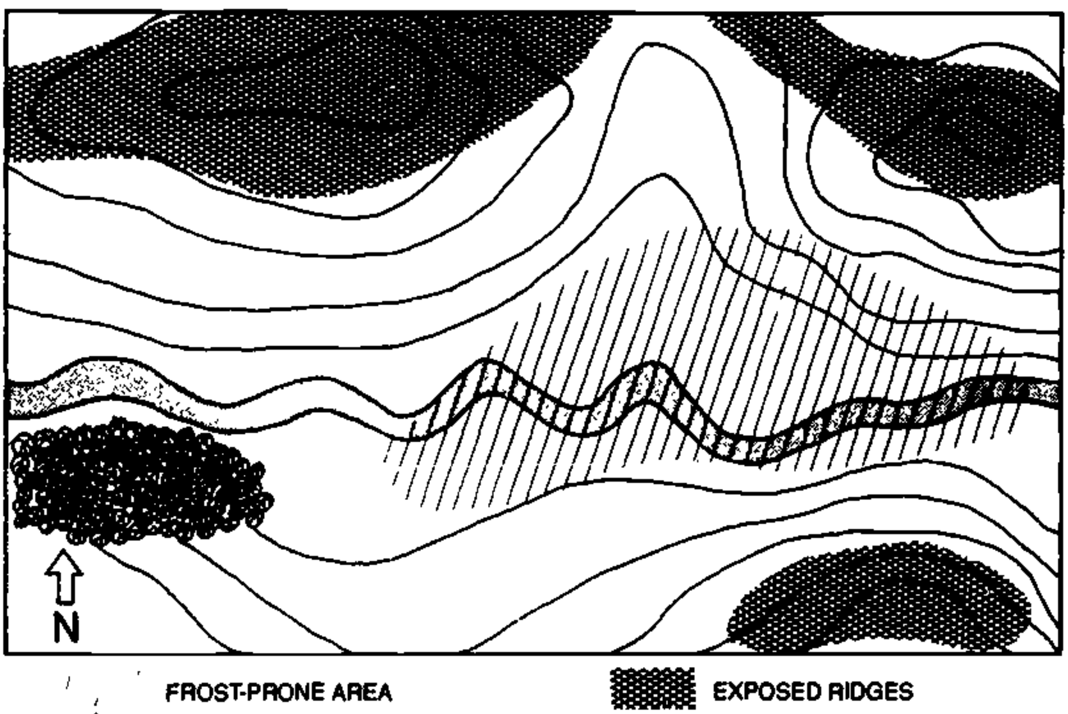
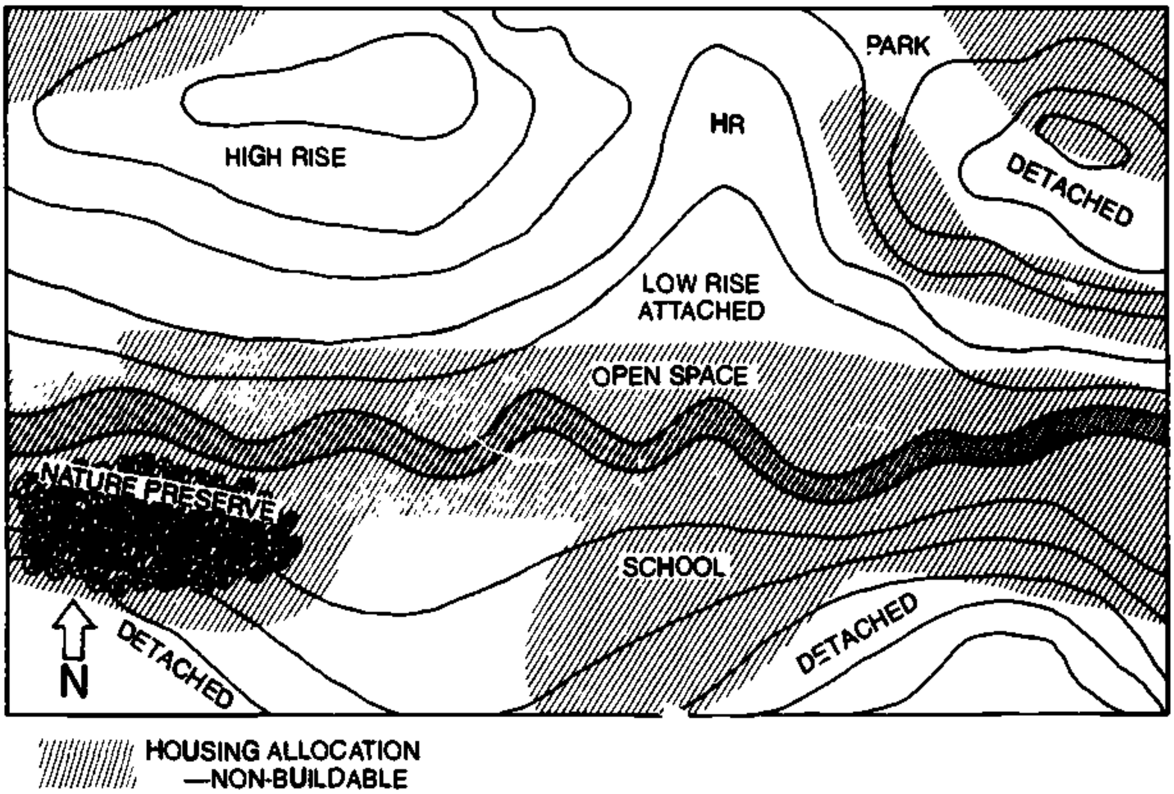


Figure 34. Land Use as Allocated on the Site



The area that remains on the site map now has both good development potential and good solar access characteristics. This buildable area, shown in figure 34, should be analyzed and housing allocations derived for the site.

At this point, preliminary site planning is finished. Housing and land uses are broadly allocated on the site according to environmental constraints and solar access requirements. The next step is to examine specific strategies for developing the site according to the development objectives and the site plan, so that solar access is maintained in those areas with good solar energy potential. This means designing land uses and housing that best use solar energy and minimize shading problems. These specific topics are presented in the following chapter.

General Design Approaches and Techniques for Solar Access

Every site planner and developer knows that each development has its own constraints and peculiarities which affect the way it is planned and built. Many of these constraints already will have been identified in the site selection and preliminary site planning stages of the development process. Still, the design of a development must in many respects be taken on a case-by-case basis. In considering solar access, however, certain basic principles *can* be applied in virtually every case to plan the development for maximum use of solar energy systems. This chapter discusses a variety of design factors that protect solar access and a number of techniques that can be used to assess potential shading in a new residential development.

The Relationship of Building and Site Design

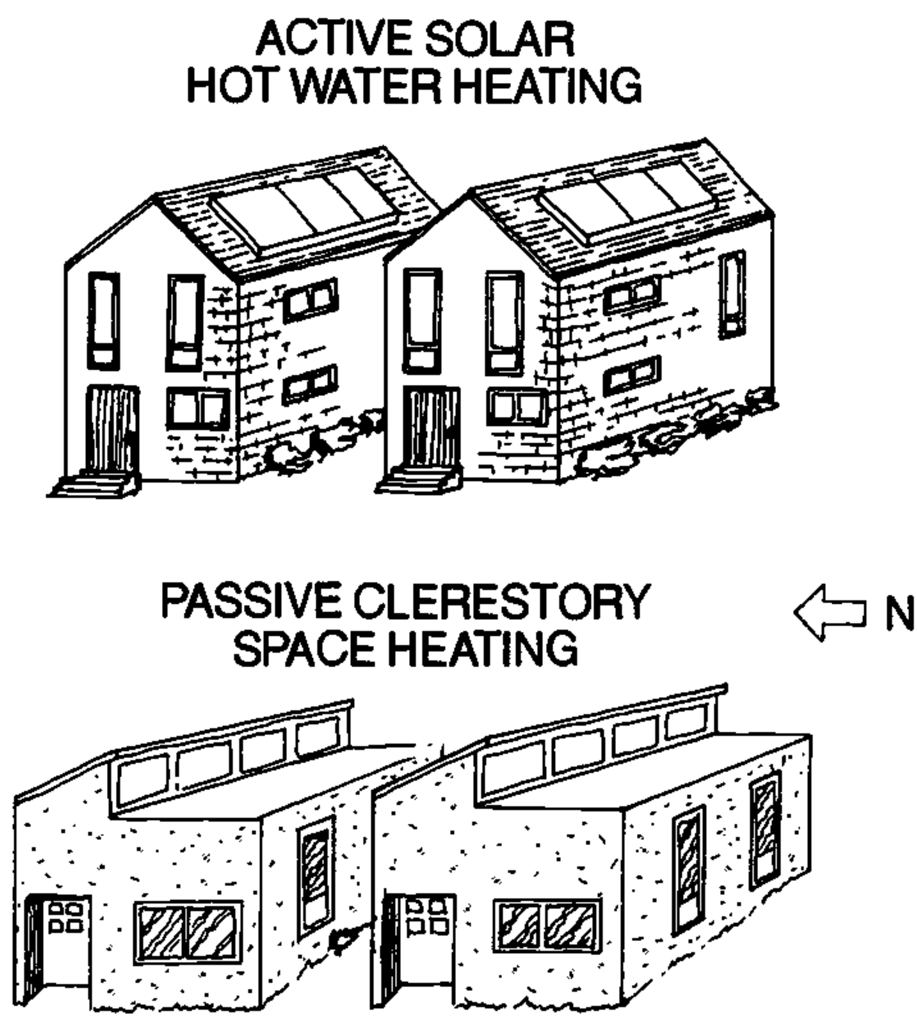
Because the number of site design options for solar energy use is relatively limited, it is essential that solar energy planners take these restrictions into account. The selection of a site and the preliminary evaluation of insolation and energy conservation suggest some broad strategies for site development to minimize problems with solar access. But the actual use of solar energy and its integration into buildings on the site might be beyond the scope of the site planner; if so, this limitation should be recognized early in the design process.

Building orientation, as we shall see, can be an important site planning concern, especially for solar space heating. But orientation also depends on the type of solar energy system being used and the probable location of the collector. These last two factors may or may not already be determined by the time the site planner begins work on the project. A design or architectural element as fundamental as roof shape and slope direction, for example, can have a significant effect on how roads, lots, and buildings are sited in order to achieve proper orientation of both the building and the collector. This interrelationship between architectural design and solar site design should be kept in mind at all times.

The Roles of the Site Planner and Architect
Ideally, the site planner should be part of the total design team from the beginning, influencing architectural decisions that affect solar energy use and recommending development layout and landscaping. Where this ideal cannot be met, the site planner or builder must accept the building design intact and design the development to accommodate the project's solar energy objectives. Realizing this objective may mean careful site planning to take advantage of natural energy-conserving features of the site, and landscaping to moderate the extremes of climate and temperatures that can affect the performance of solar equipment.

Similarly, the architect, when designing buildings which use solar energy for space heating, water heating, or space cooling, should be responsive to the site's limitations. Site location or shape may suggest building layouts in which broad areas of the roofs or south walls cannot be oriented properly for maximum solar access. In these situations, it is up to the architect to develop alternative collector and building designs. If building facades cannot be oriented east-west, for example, solar access must be limited to roof-mounted collectors or to a roof design using clerestory windows or skylights. Roof-top collectors, whether active or passive, can bring light

Figure 35. Building Design Can Assist Solar Access



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and solar radiation into a dwelling which otherwise cannot receive sunlight along its longest wall (figure 35).

This flexibility might also extend to fundamental decisions regarding the type of solar energy system to be used in the development and the location of solar collectors on a building. Roof-mounted collector arrays are less likely to be shaded than south-facing windows simply because of their greater height. Domestic water heating collectors are generally small enough so that they can be located on a lot or building beyond shaded areas. Both allow site planning flexibility. On the other hand, passive space heating systems offer fewer site planning options, particularly with respect to solar access.

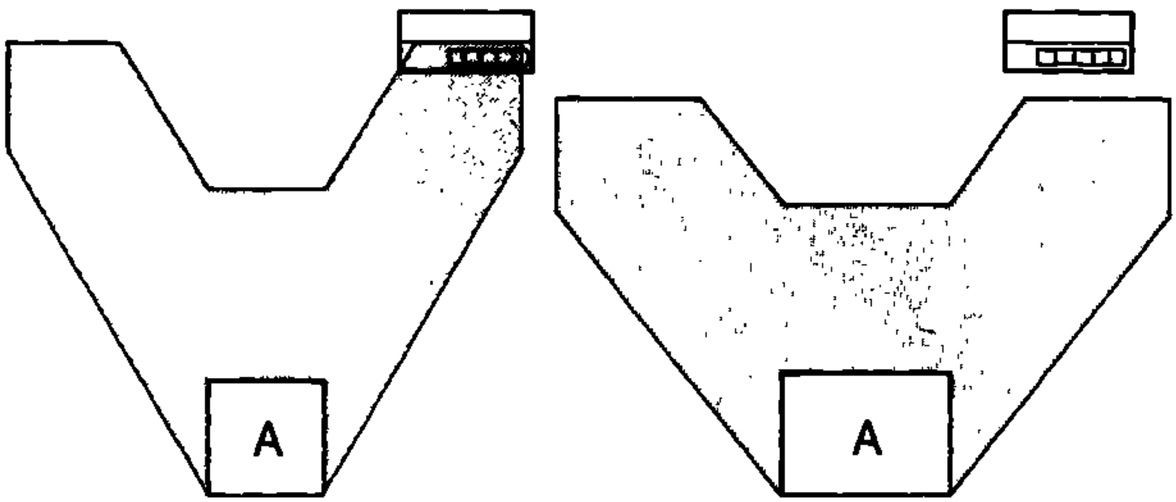
Building Height and Site Planning

Another example of the relationship between architecture and site planning involves building heights. An obvious way to reduce shading by buildings is to lower their height. In higher latitudes, on north slopes, or in higher density developments, reducing building heights is a viable option to provide better south-wall solar access.

The amount of the height reduction to protect solar access depends on the shadow lengths created by latitude, topography, and the sun's position in the sky. The developer must first look at ways to protect south-wall access. If there is a small difference, say only a few feet, the reduction may be more strongly justified. If not, then the developer may have to settle for rooftop access or whatever limited south-wall access is possible at the existing height.

The necessary reduction in building height can be determined by using the shadow pattern or north shadow projection techniques discussed in Appendix III, or by drawing cross-sections of the development and examining the critical solar angles. Proposed building heights are incrementally reduced until the shadow pattern or shadow projection fits within the lot and road width dimensions established by the preliminary site plan (and, of course, by local regulations).

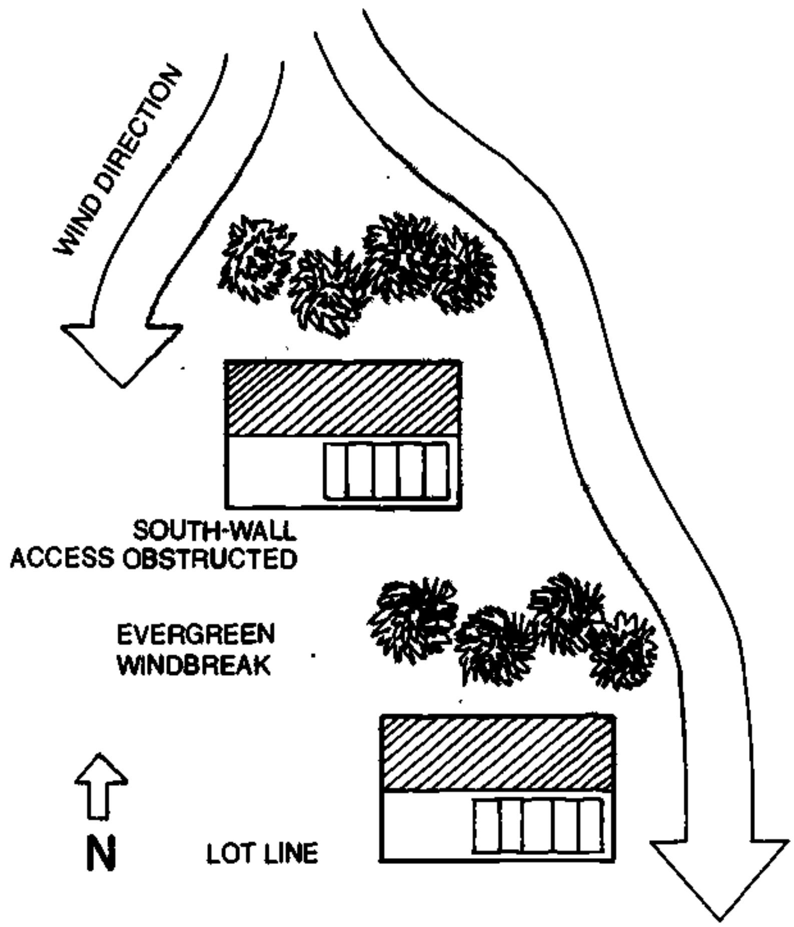
Figure 36. Reducing Building Height to Improve Solar Access



SHADING BY 35′
BUILDING A

NO SHADING IF BUILDING
A REDUCED TO 28′ HEIGHT

Figure 37. Windbreaks as Solar Access Obstructions



This architectural solution applies only to low-rise housing (such as townhouses, duplex and multiplex housing) and single-family detached housing. High-rise and mid-rise apartments are designed for maximum density; to lower them in height might require too much land. Lowering building height, therefore, may not be the best approach for all developments and all types of housing.

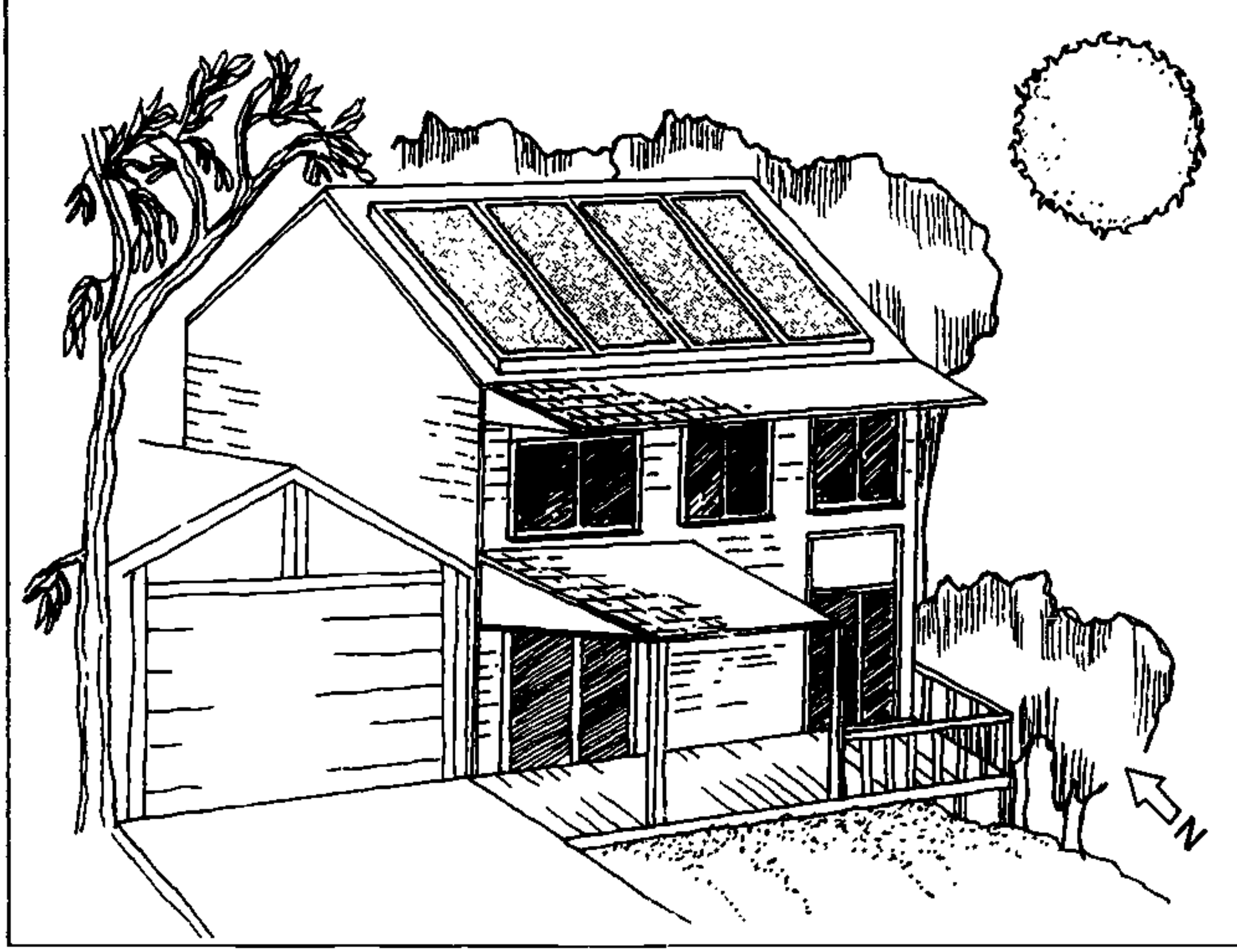
Site Planning and Energy Conservation

Any solar heated or cooled building can profit by energy conservation and energy-conserving site design. Optimal building orientation affects a structure's heat gain or loss, thus making the use of solar energy for space cooling or space heating purposes more effective. Sensitive site planning can also protect buildings against heat loss caused by cold winter winds and assist the natural cooling of buildings in warmer regions by increasing the wind flow through the structure.

As with collector and building orientation, energy conservation requires close cooperation between the members of the design team. Solar buildings must be energy conserving to operate effectively, yet site planning can moderate climate and temperature only to a limited extent. It is up to the solar designer or architect to design buildings that take maximum advantage of local climatic conditions to maintain comfortable temperatures within a structure. Energy-conserving site planning can assist a building's solar performance only if the building itself is designed to take into account the local climate. Site planning alone cannot assure adequate solar energy performance.

One way in which energy-conserving site design affects solar access is by reducing the size or number of solar collectors needed to maintain

Figure 38. Large Expanses of Roof and Wall Oriented to the Sun



adequate heat or coolness in a structure. A building that is tempered against the extremes of wind, temperature, and climate requires less total collector area than does a structure that ignores the energy-conserving features of a site (figure 29). Besides reducing costs, energy-conserving site planning permits greater flexibility in locating the collector. The collector area required for space heating in cold climates, for example, can be reduced significantly if energy-conserving site planning is used. The collector can even be located on a lot or building outside an area shaded by adjacent vegetation or buildings and permit greater flexibility in both building design and development layout.

The developer or site planner must be aware of possible tradeoffs, however, between energy conservation and solar access. For example, a landscaping plan that channels wind through buildings or that protects a cluster of buildings against the cold winter winds can also cast appreciable shadows across collector locations, as in figure 37. Similarly, the arrangement of buildings on a site to minimize heat loss by winter winds can also result in less than optimal solar orientation. In some cases, this can be corrected by modifying the design of the structure to orient the collectors properly, but in other cases alternative building layouts may have to be considered to assure proper solar access.

Building Orientation and Solar Access

In solar access planning, buildings should be oriented so that large areas of the roof and walls receive solar radiation from the south. The purpose is both to maximize solar radiation and to control the structure's heat gain and heat loss.

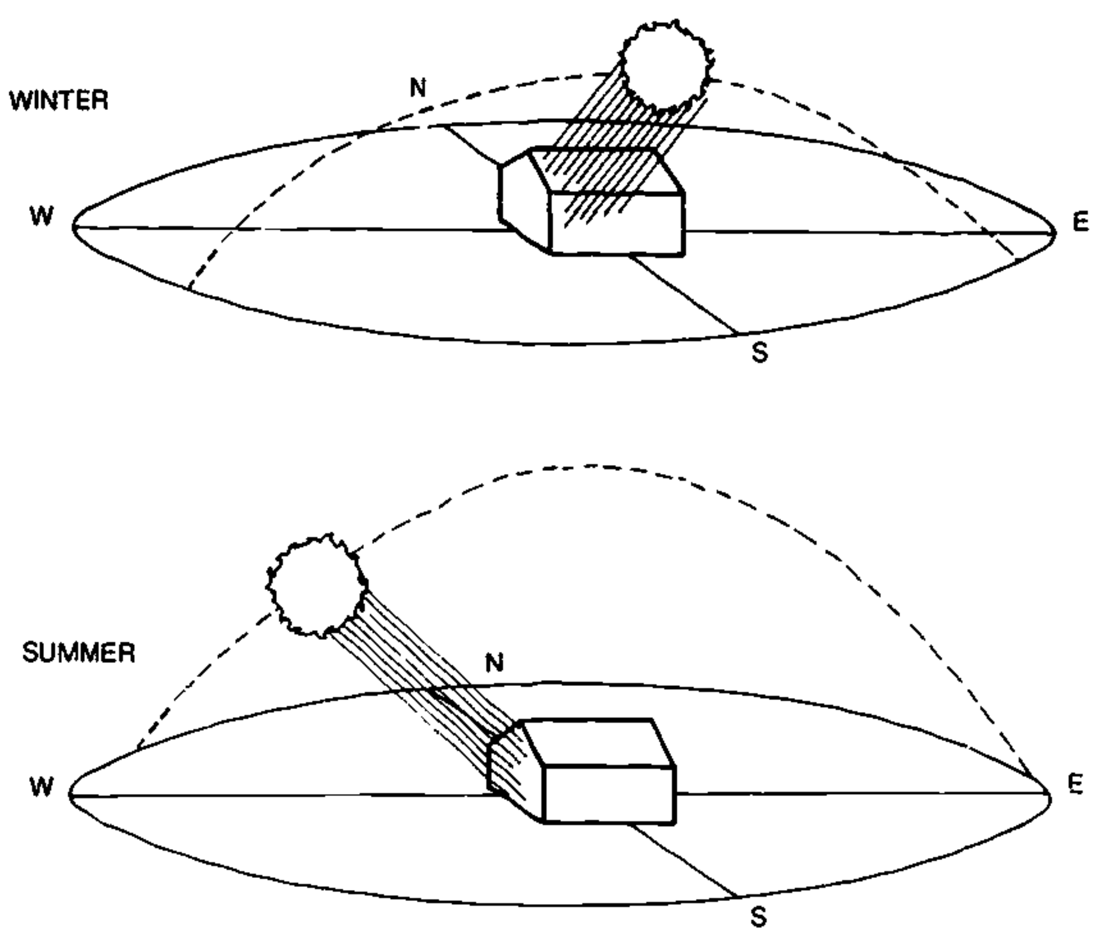
In discussing orientation, it is useful to speak of a building's axis, the direction of the building along its longest dimensions. Because most single- and multifamily housing is rectangular in plan, the axis runs parallel to the building's longest sides. To receive maximum exposure to solar radiation and to minimize heat loss, buildings should be oriented with their axes running in an east/west direction, as figure 38 illustrates.

This general orientation rule applies for most types of buildings and for most areas of the country. In regions where solar energy is used predominantly for heating, the building's east/west orientation exposes the longer walls and roof areas to the greatest amount of winter sunlight but offers the least exposure to the hot afternoon sun of summer, as figure 39 shows. In warmer climates, moreover, an east/west building axis allows the best use of overhangs and trees for shading walls and windows and also prevents large areas of the structure from being exposed to the afternoon sun. Orientation, then, becomes as much an energy-conserving factor as it is a solar access factor.*

*See, for example, "Energy and the Builder. Proper Site Orientation Saves Energy," pp 83-91

Figure 39. Proper Orientation on East/West Axis—

GOOD WINTER ACCESS FOR HEATING AND SMALL AREA OF BUILDING VULNERABLE TO SUMMER OVERHEATING



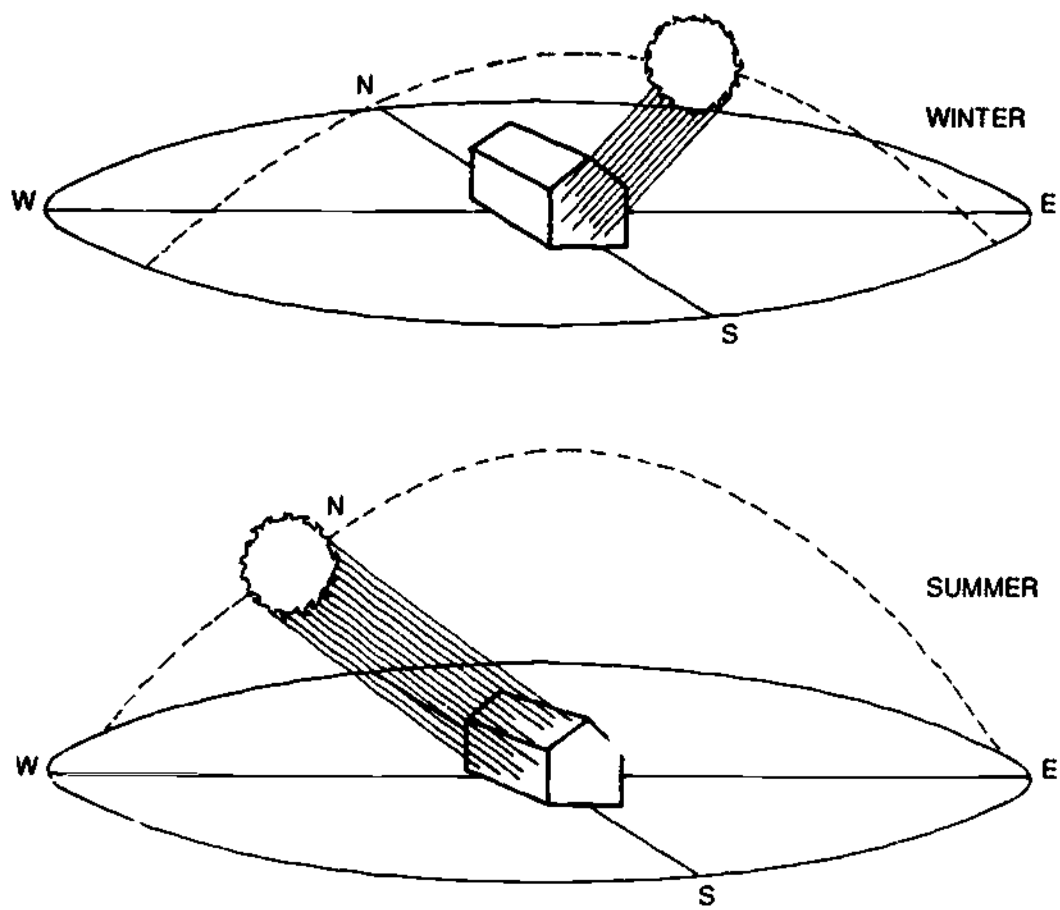
To compensate for improper orientation, wall and window areas can often be shaded with sun-screens or overhangs to reduce heat gain to a building in the summer. Similarly, deciduous or evergreen trees or tall shrubs can act as a shield against the hot summer sun. But shading becomes more difficult to use the more the building is off the east/west axis. Improper orientation can result in summer air conditioning costs that offset the savings gained from solar heating use in winter. Figure 40 illustrates the effect of improper orientation on a building's energy efficiency.

Collector Orientation and Building Orientation

The principle of east/west axis orientation applies to the siting of the building, not to the solar collector. Provided that the collector is aimed generally south, its orientation has only a minimal effect on its efficiency; substantial variations from a due south orientation can be tolerated without a serious reduction in the collector's effectiveness. Figure 41 shows that a collector can be oriented 35 degrees from due south and still be 95 percent efficient.

Figure 40. Improper Orientation on North/South Axis—

POOR WINTER HEAT GAIN AND LARGE AREA OF BUILDING VULNERABLE TO OVERHEATING

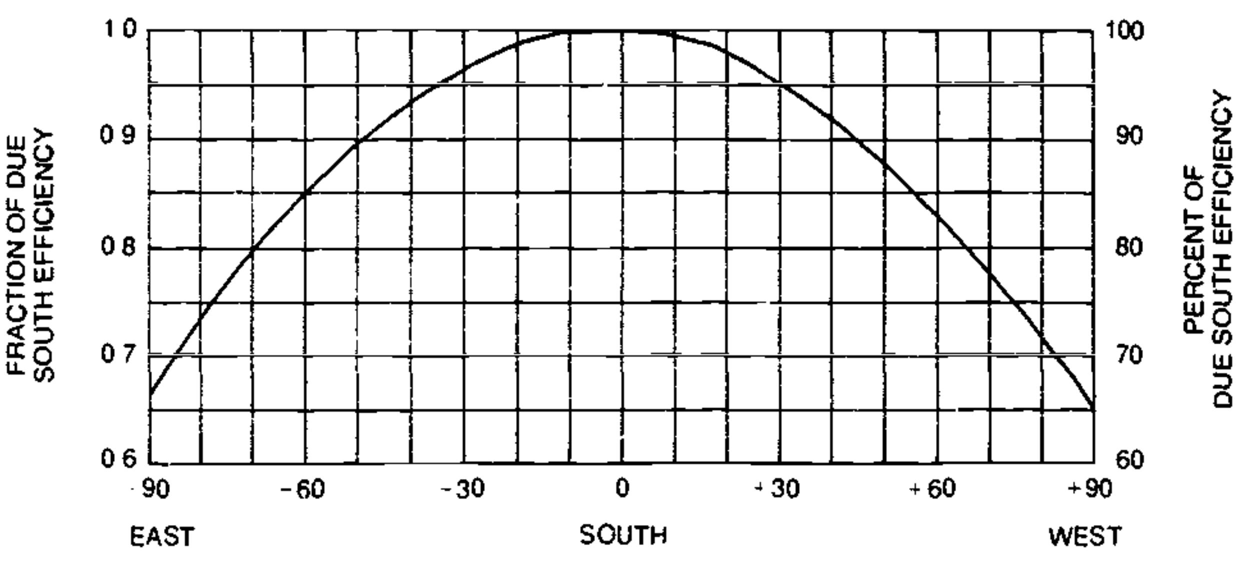


The relationship between collector orientation and building orientation is subtle, yet crucial. In the case of passive solar energy systems, the building's orientation is also the collector's orientation, especially when south glazing is incorporated into the building itself. For active solar energy systems, there is greater flexibility in collector orientation, depending on the roof's shape and orientation (for rooftop collectors) or on the orientation of the collector mounting. Building orientation becomes important only to the extent that proper orientation enhances energy conservation. For domestic water heating, building orientation becomes less important. Active or passive water heaters depend less on the orientation of the building than on the orientation of the collector.

Orientation Guidelines for Single-Family Housing
The typical single-family detached house is separated from its neighbors and its access road by front, side, and rear yards; in this instance, orientation for solar energy use is not a crucial factor, provided that the design of the structure can be accommodated to the variation from the ideal east/west axis orientation described above. Although the axis of detached structures can tolerate several degrees' difference from the ideal east/west axis, a less-than-perfect orientation must be taken into account. Thus, the windows and south walls must be shaded from the effects of the hot summer sun to prevent overheating in summer.

The axes of passively heated homes or buildings that rely on passive south-facing collectors

Figure 41. Effect of Solar Collector Orientation on Annual Heating Performance*

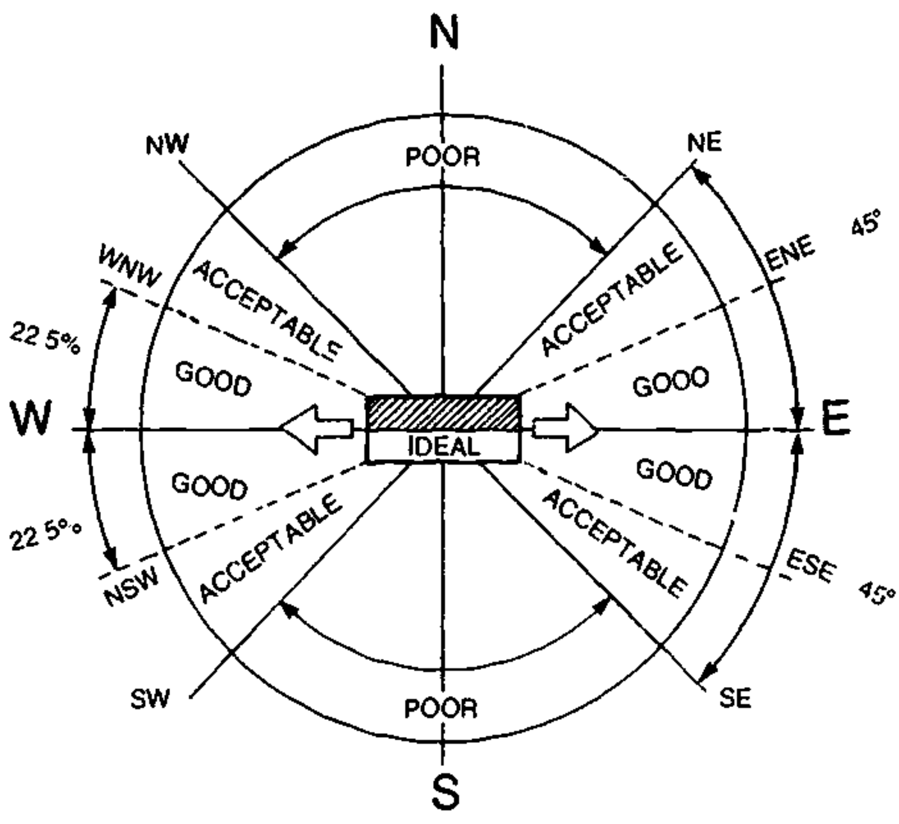


*Based on Colorado State University Solar Energy Applications Laboratory *Solar Heating and Cooling of Residential Buildings* pp 14-18 to supplement the heat generated by active collectors can be sited up to 45 degrees away from east/west orientation; a variation of up to 45 degrees can be tolerated. In other words, the building axis can swing as far as northeast/southwest or northwest/southeast without seriously affecting the solar access or thermal characteristics of the building, provided that awnings, sunshades, or overhangs are used to prevent overheating. The developer who fails to consider the problem of overheating in summer will find that the energy savings from space heating by solar energy in winter are more than offset by high air conditioning costs in summer.

Better shade control is possible if the building axis is restricted to 22.5 degrees either side of the ideal east/west axis orientation. Not only are awnings and other architectural devices more effective in such cases, but the side walls also can be shaded more easily by trees or accessory buildings. By restricting orientation from ESE/WNW to WSW/ENE, more roof area is given a south access, and active solar collectors can be integrated with the structure. Figure 42 shows the optimal and critical orientation guidelines for detached housing.

In siting buildings to meet these guidelines, the critical factor is likely to be road orientation. Because most local regulations require building lines to follow lot lines and lot lines to follow roadway alignment, building lines follow the line of the street. Most new single-family residential developments, therefore, are built so that the long axis of the building runs parallel to the frontage

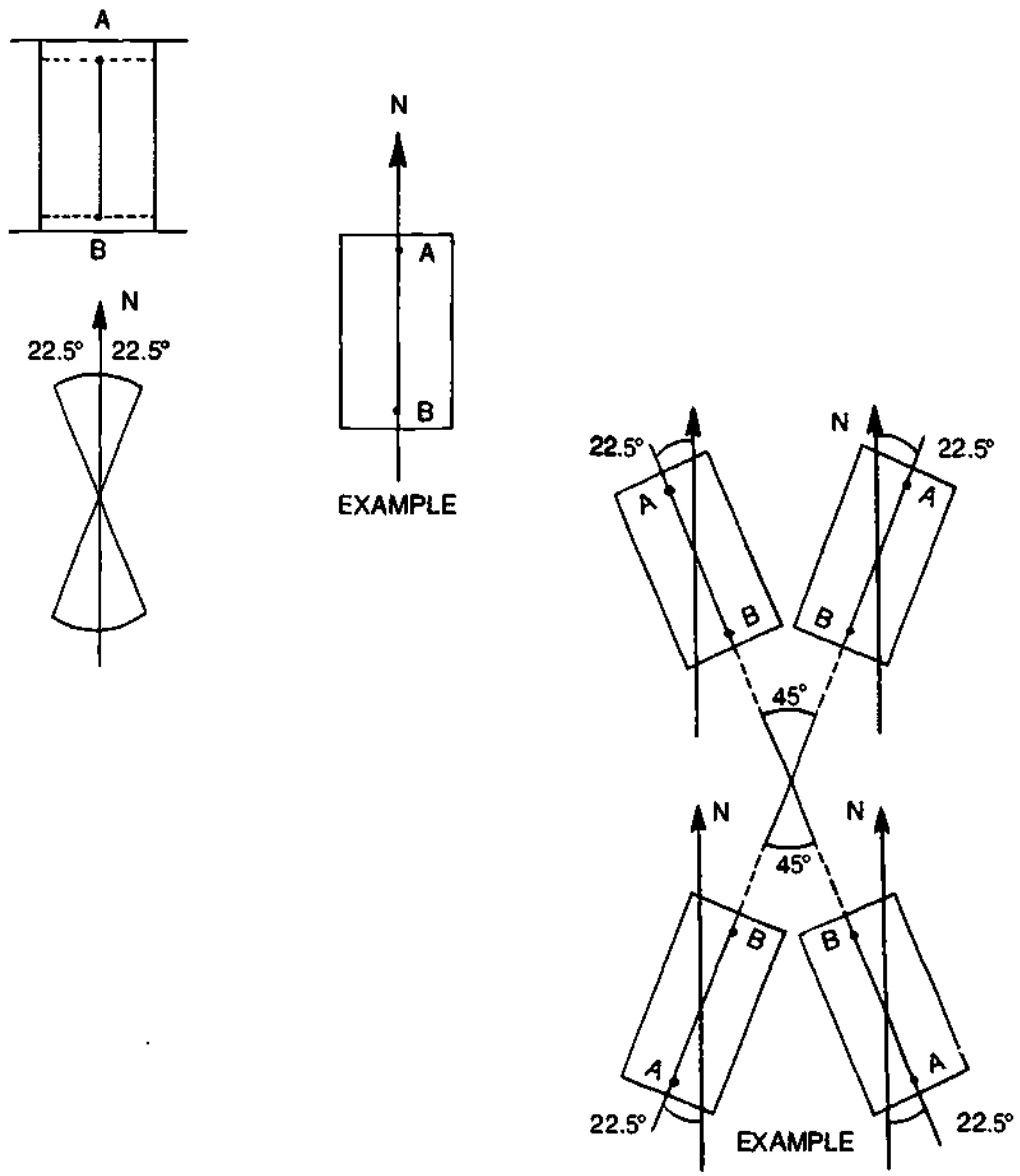
Figure 42. Long Axis Orientation for Detached Housing



45° VARIATION FROM IDEAL EAST/WEST ORIENTATION IS ACCEPTABLE, AND A MAXIMUM 22.5° VARIATION IS BETTER, TO ASSURE PROPER WINTER HEAT GAIN AND SUMMER SHADE CONTROL.

Figure 43. Sacramento County, California, Lot Orientation Criteria

A STRAIGHT LINE DRAWN FROM A POINT MIDWAY BETWEEN THE SIDE LOT LINES AT THE REQUIRED FRONT YARD SETBACK (POINT A) TO A POINT MIDWAY BETWEEN THE SIDE LOT LINES AT THE REQUIRED REAR YARD SETBACK (POINT B), IS ORIENTED TO WITHIN 22.5° OF TRUE NORTH.



ANY RESIDENTIAL LOT ORIENTED WITH THE 45° ARCS ILLUSTRATED IS CONSIDERED TO MEET THE REQUIREMENTS FOR SOLAR ORIENTATION.

road, with the building facing the street. Some jurisdictions are changing this practice. Sacramento County, California, requires all lots in new residential developments to be oriented within 22.5 degrees from south, thus assuring a generally east/west road (and building) orientation.*

For communities without roadway orientation requirements, proper building orientation can be achieved by following the guidelines discussed in the next chapter. The developer or site planner should also remember that proper building and roadway orientation have the greatest effect on passively heated homes, a considerable effect on actively heated structures with collectors integrated into roofs, and the least effect on domestic water-heating collectors.

Orientation Guidelines for Multifamily Housing

East/west orientation simply may not be possible for all types of housing. Duplexes, row and townhouses, quadruplexes, and low- and mid-rise apartments all have slightly different solar access requirements and, therefore, different orientation concerns.

*This ordinance and supporting memoranda are discussed in the APA companion guidebook. *Protecting Solar Access in New Residential Development: A Guidebook for Planning Officials*

Duplexes are two-unit structures sharing a common wall. Ideally, for solar access to be provided to both units, the duplex should be oriented on an east/west axis with the common wall bisecting the structure north and south. If the structure is oriented with its long axis north and south, then one unit will have most of its wall area exposed to the morning sun, and the other unit's wall will be exposed to the afternoon sun and overheated in summer. In addition, both units will have poor solar access in general. Finally, if the units are aligned east/west and have their dividing wall aligned east/west, only the southerly unit will have good solar access; the northerly unit will have no access to sunlight unless skylights or clerestory windows are used. Figure 44 illustrates these cases.

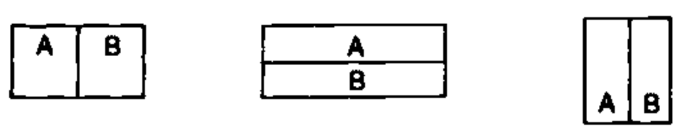
When duplex units are stacked, the axis should be oriented from east to west like a single-family house. In this way, both units have south-wall exposure. While the lower unit does not have its own rooftop area for active collectors, shared collectors over the second-floor unit or a detached collector can be used.

Quadruplexes are structures containing four units with several common walls. Solar access is difficult to achieve for all four units, although the limited access can be maximized by proper

Figure 44. Duplex Orientation

Building Axis	E/W	E/W	N/S
Common Wall Orientation	N/S	E/W	N/S

Building Shape

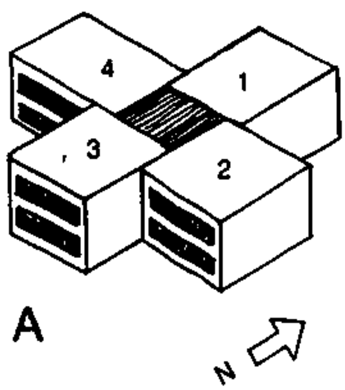


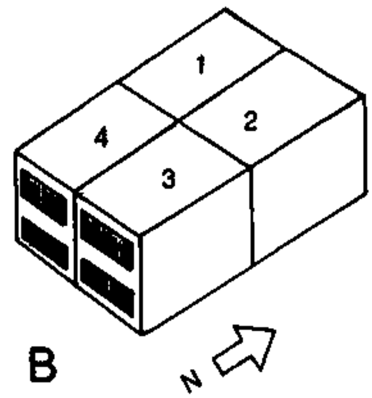
Solar Access	BEST Both A & B have good access	POOR Even with skylights, A has less access	WORST Both have poor access and overheat

Figure 45. Quadruplexes

UNIT	SOLAR ACCESS
1	Roof /
2	Roof / South, east wall
3	Roof / East, south, west wall
4	Roof / West, south wall

UNIT	SOLAR ACCESS
1	Roof / West wall
2	Roof / East wall
3	Roof / East, south wall
4	Roof / West, south wall

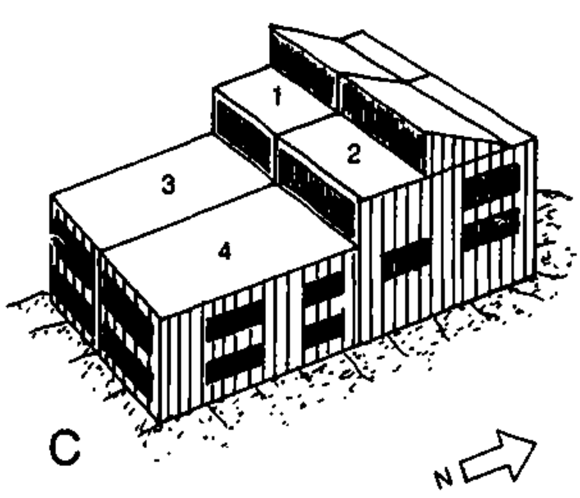




orientation. Figure 45 shows two common quadruplex arrangements. Both have poor solar access. In A, Unit 3 shades Units 2 and 4 while Unit 1 has no access at all. In B, only Units 3 and 4 have south access.

The best solution to this orientation problem might be to modify the design of the unit. In the designs in figure 46, all units have good access.

Figure 46. Changing Quadruplex Design



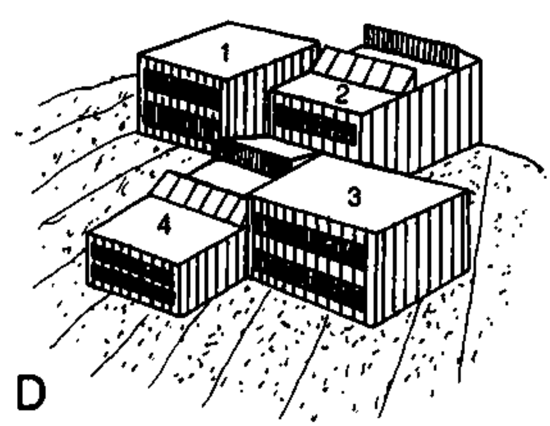
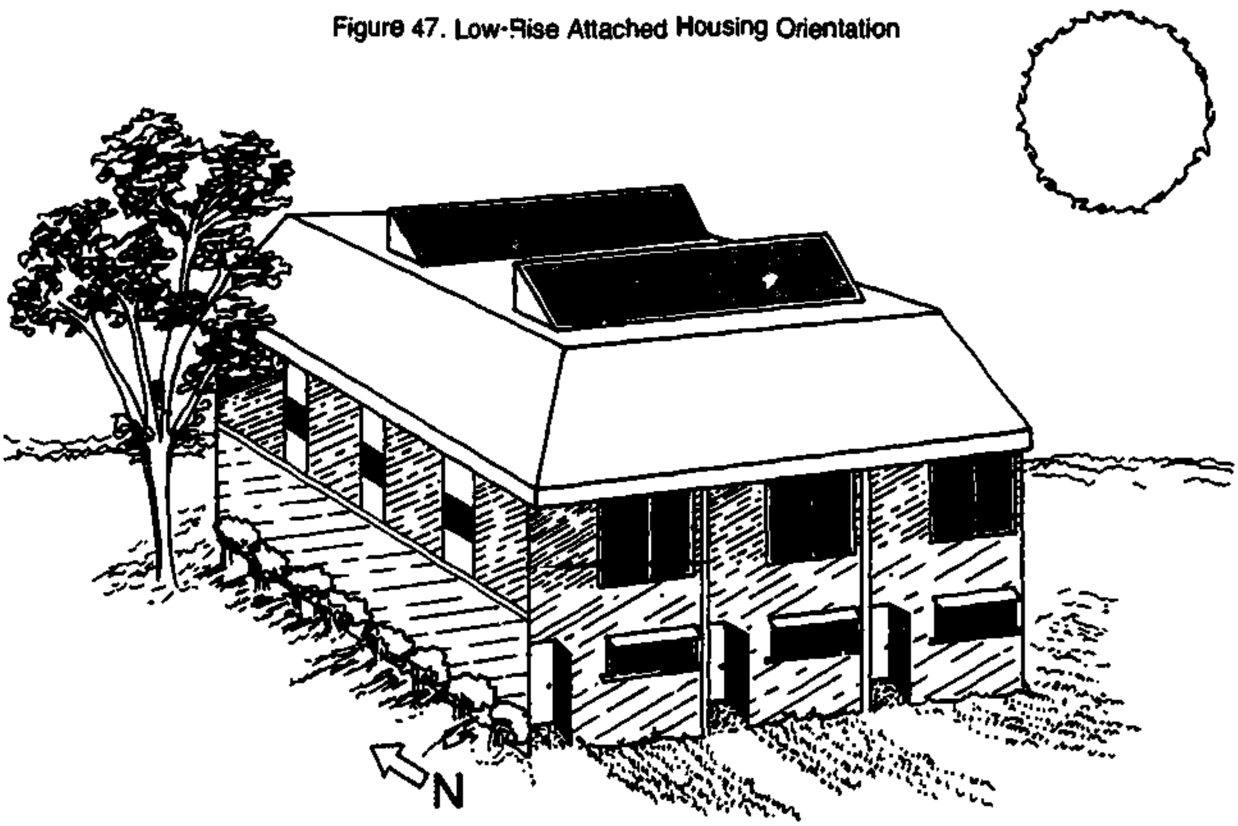


Figure 47. Low-Rise Attached Housing Orientation

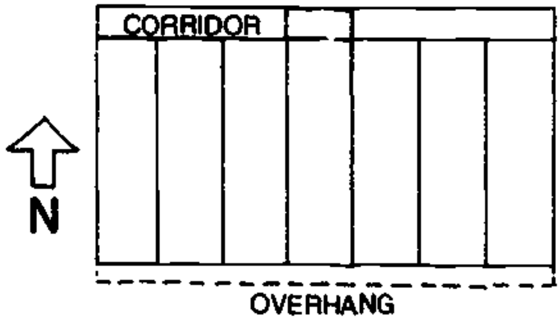


Low-rise apartments, row houses, and *townhouses* all follow similar orientation guidelines. In these structures, the individual units should be oriented with their axes north/south, with the whole complex oriented east/west. This gives each unit one wall with a south access, thus assisting the structure's heating system during the winter months and allowing for proper shading during the summer to reduce air conditioning use. (See figure 47.)

High-rise and *mid-rise housing* has a great range of possible forms. Four common shapes are the single- and double-loaded corridor buildings (figures 48 and 49), the cruciform building (figure 50), and the tower block (figure 51). For all four shapes, orientation of individual units is a key consideration. The ideal is the single-loaded building with most of its windows facing south and the long axis running east/west. Double-loaded buildings, however oriented, can expect limited solar access; an east/west alignment of individual units means probable overheating in summer, while a north/south alignment means half the units will have no direct sunlight during winter.

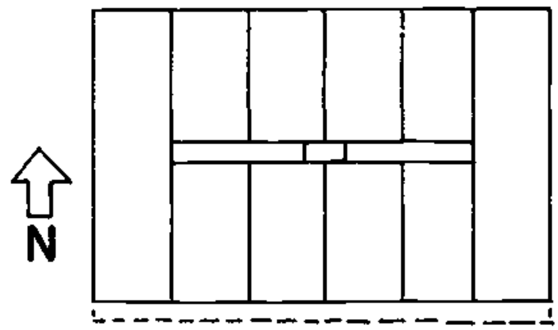
Tower blocks also need as many south windows and as few east/west windows as possible. In cooler climates, towers with four units per floor can be oriented northwest/southeast to provide good solar access for three of the four units. Cruciform plans are even better, although special care must be taken to shade southeast and southwest windows in summer.

Figure 48. Single-Loaded Corridor



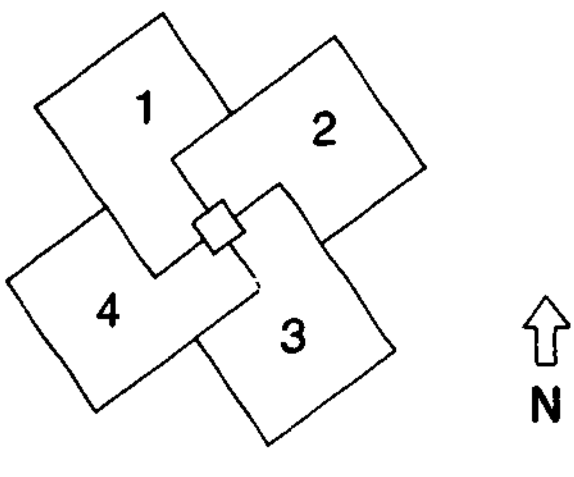
SINGLE-LOADED CORRIDOR;
ALL UNITS HAVE SOLAR ACCESS

Figure 49. Double-Loaded Corridor



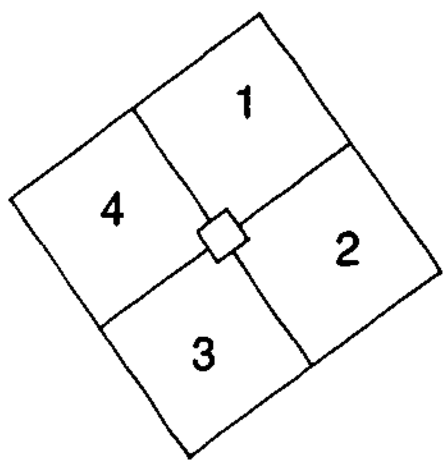
DOUBLE-LOADED CORRIDOR;
HALF THE UNITS HAVE SOLAR ACCESS

Figure 50. Cruciform High-Rise Onentations



ALL HAVE SOUTHEAST OR SOUTHWEST ACCESS

Figure 51. Tower Block High-Rise Orientation



#1 LACKS ACCESS.

Techniques for Analyzing Solar Access

Although the layout of a development with solar access is quite similar to conventional development design, and although many of the analytical techniques used in environmental site planning are equally applicable to solar developments, the site planner or developer can profit by considering some techniques peculiar to solar development.

Two such techniques, which may be unfamiliar to many developers, can provide both a quick and easy overview of solar access within a development; they are shadow pattern analysis and shadow projection analysis. Shadow pattern analysis, as we saw in the first chapter, involves laying out the shadow pattern that buildings and landscaping cast during the period of maximum solar energy use. Shadow projection analysis is a drafting shortcut that can be applied to developments using passively heated buildings which have south-wall access requirements.

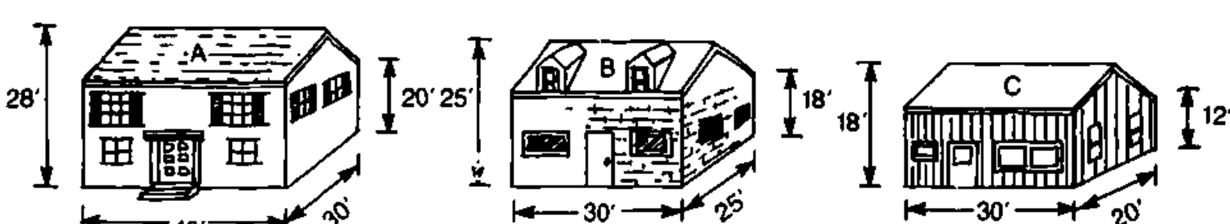
Analyzing Shadow Patterns

Proposed buildings and landscaping in a development can be analyzed for solar access by using the techniques described in Appendix III. Buildings and trees can be abstracted into a series of poles, corresponding to the height of the structure or tree, and shadow lengths predicted for each pole position. The composite of the pole shadows gives an approximation of the total shadow that the object will cast.

Shadow patterns can be standardized for buildings and vegetation, provided that the terrain is relatively uniform and the buildings themselves are similar. Once the developer or site planner develops several shadow patterns to accommodate the anticipated structures in the development, these patterns can be moved about the base map which was developed in the preliminary site planning section; then a rough estimate of anticipated shading can be assessed.

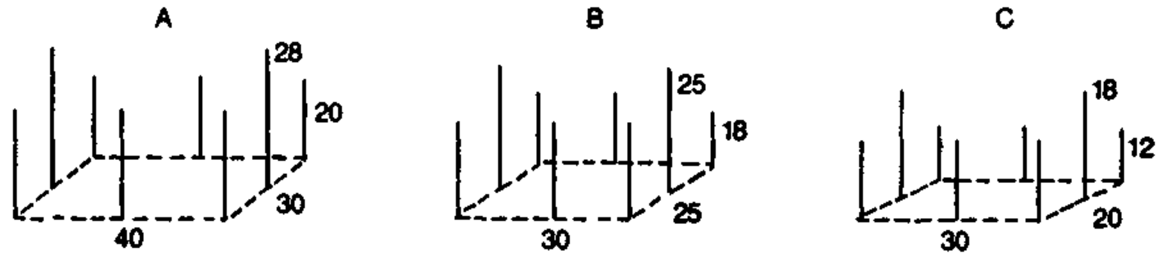
Where the terrain is uniform, and building dimensions known, the following procedure can be used:

Step One: Identify major building types and dimensions in the development.

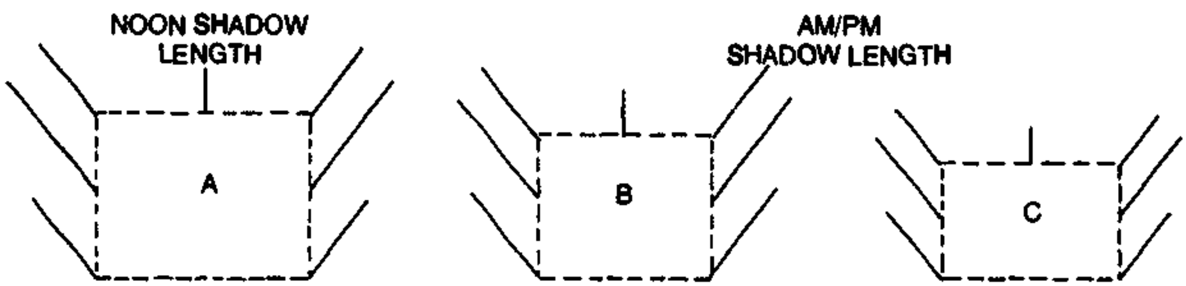


2-STORY 1½-STORY 1-STORY

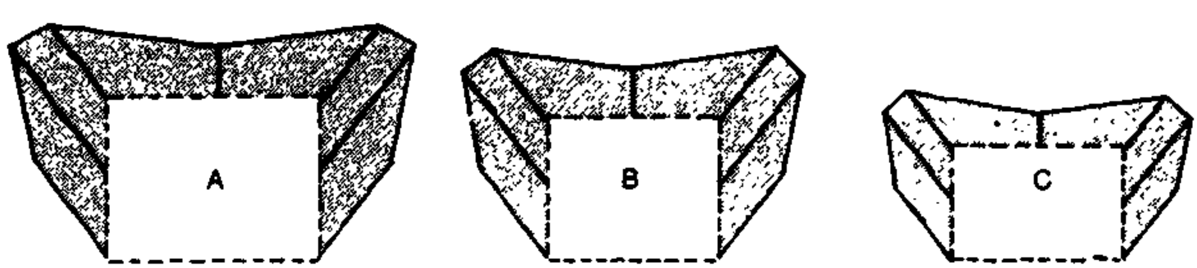
Step Two: Abstract the buildings into a number of poles.



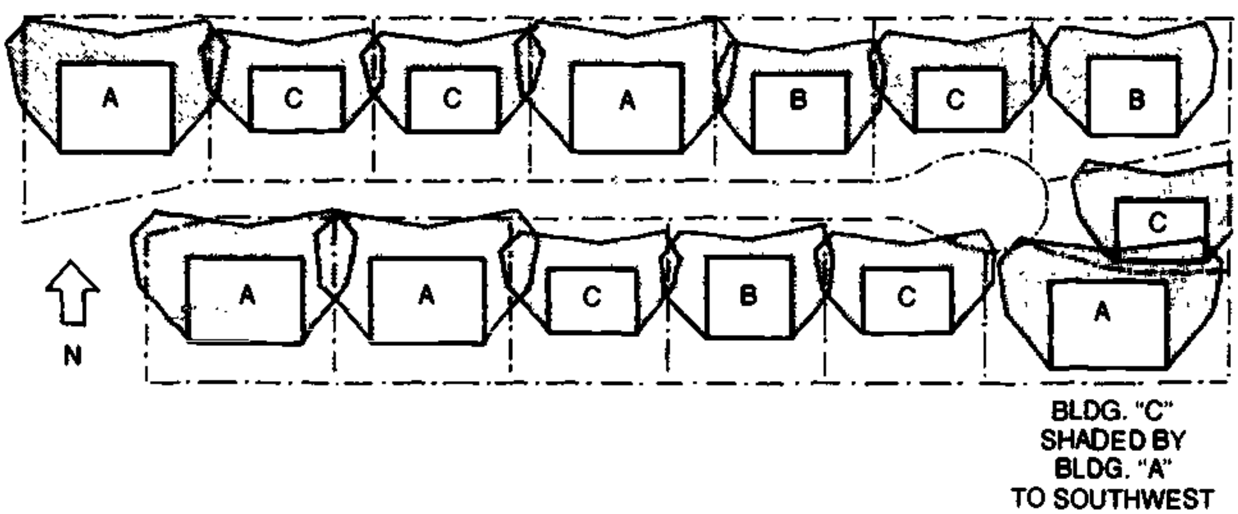
Step Three: Develop shadow lengths for each pole, based on skyspace azimuths.



Step Four: Connect the shadow length lines from the poles to derive the shadow pattern of the building.



Step Five: Make a template of the building shadow patterns and arrange the shadow patterns on the site so that shading is minimized.



The procedure is different on sites where the slope changes radically. Instead of using shadow templates for the various building types, the site planner or developer must construct individual shadow patterns for each structure, based on the terrain. Slope direction and gradient change the shadow lengths and shadow patterns. The shadow lengths tables in Appendix III must be consulted for each change in terrain and building dimension.

A similar approach can be used when the developer does not intend to build the project but merely intends to subdivide and improve the land for others to develop. In this case, the developer or site planner must approximate the final dimensions and locations of the buildings on the lots. The easiest way to do this is to examine the zoning ordinance and other regulations. Zoning ordinances frequently establish maximum height restrictions, and this height standard can be used to develop approximate shadow lengths for hypothetical poles for future buildings. Similarly, if maximum density is desired, then the buildable area of the lots can be approximated by taking the subdivision plat and subtracting zoning setbacks from the lot line boundaries. What results is a definition of the largest possible structures that legally can be built on the site. Figure 52 illustrates this technique.

The developer or site planner might find this approach too restrictive to meet density objectives because it assumes a maximum buildout that may never occur (even if it is allowed under local regulations). As an alternative the developer can examine nearby, completed developments whose residents represent the target group for marketing. The site planner or developer can assume that similar buildings of similar dimensions will be built in his subdivision and can base his shadow pattern templates on these existing structures.

Figure 52. Shadow Patterns for Subdivision Lots

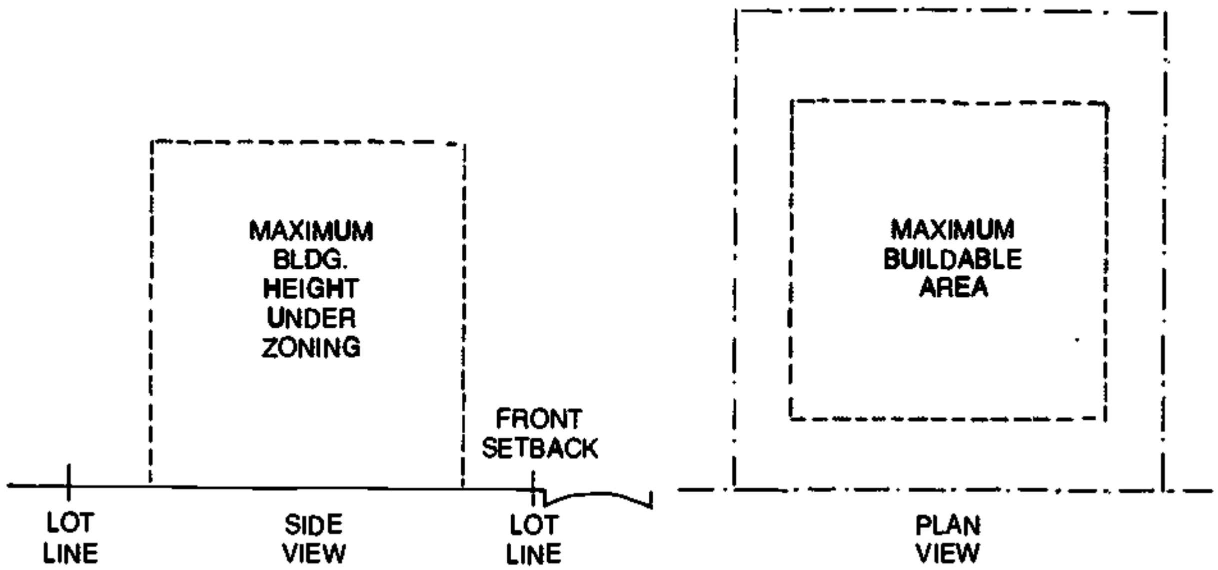


Figure 53. North Shadow Projection Distance Compared to Shadow Pattern of a Pole

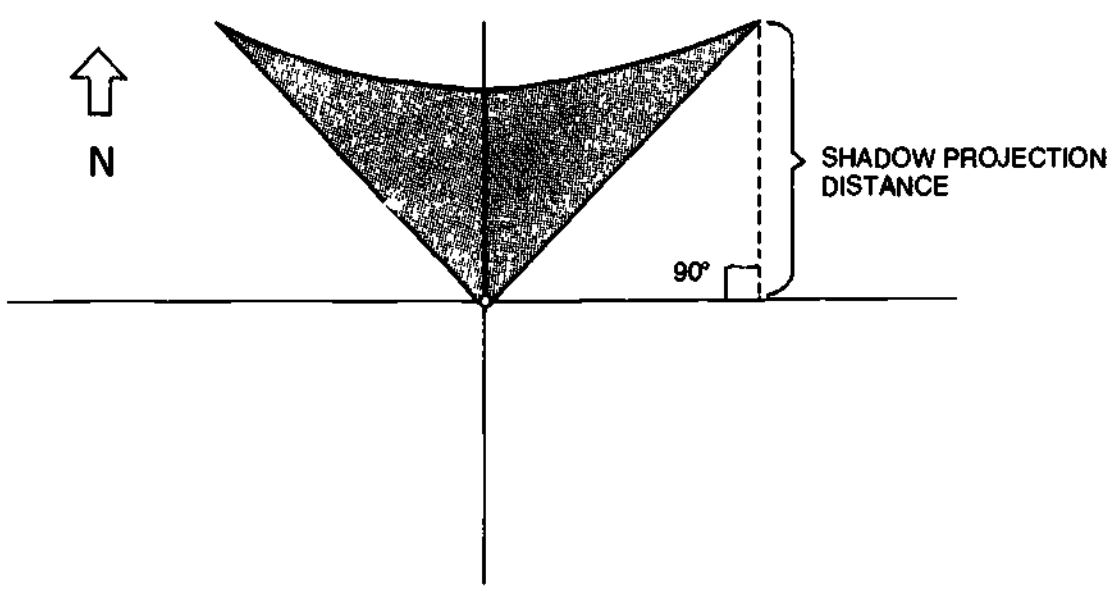


Figure 54. North Shadow Projection Table

RATIO OF NORTH PROJECTION OF SHADOW LENGTH TO HEIGHT OF SHADOW CASTING OBJECT*

South Slope	20%	15%	10%	5%	Flat	5%	10%	15%	20%	North Slope
25°	1.1	1.2	1.3	1.4	1.5	1.6	1.8	1.9	2.1	
30°	1.4	1.5	1.6	1.7	1.9	2.1	2.3	2.6	3.0	
35°	1.6	1.8	2.0	2.2	2.5	2.8	3.3	3.9	4.8	
40°	2.0	2.3	2.5	2.9	3.4	4.0	5.1	6.8	10.2	
45°	2.5	2.9	3.4	4.1	5.1	6.8	10.4	21.5	—	
48°	2.9	3.5	4.2	5.3	7.2	11.2	25.4	—	—	

*These figures are approximate. At some of the higher latitudes and steeper slopes, rounding off may result in slight error. For further discussion, see Appendix III.

Analyzing Shadow Projections

A north shadow projection is the furthest point north that a shadow reaches. Analyzing north shadow projections is a quick method to determine solar access for a proposed development and can be used as a rough method to assess the effect of shadows in a residential project. In order to prevent shading of the collector, the planner or developer can use the shadow projection technique to determine the minimal distance needed between the collector and objects lying to the south of it. This method is most useful in developments where south-wall access is an objective and where streets are oriented in an east/west direction.

While the shadow pattern technique is the most accurate representation of how much space a specific shadow covers, a shadow projection is still useful for a broad-scale analysis of an entire development. The shadow projection distance can be used, for example, to determine the minimum spacing between two rows of townhouses or detached structures situated north and south of each other, and, ultimately, to determine the maximum development density that will meet solar access requirements. Techniques for determining density using this technique are present in Appendix IV.

As figure 53 shows, there is a geometric relationship between shadow length and north shadow projection. The greater the shadow length, the farther north the shadow projection distance. The very factors that affect shadow length—north/south slopes, latitude, and shadow azimuth angles—also affect the north shadow projection distance. In most cases, the shadow projection distance will be less than the shadow length during the morning and afternoon, but it will be greater than the noon shadow length for an object of uniform height.

Shadow projections can be derived from figure 54. The values in the table represent the ratio of the north projection of a shadow's length to the height of the object casting it. To find the projection of a 10-foot pole at 30 degrees north latitude on a flat surface, multiply 1.9 (the value for the north projection obtained from the chart) by 10. Thus, 19 feet is the furthest distance north that the shadow of a 10-foot pole at 30 degrees north latitude will reach (between the morning and afternoon cutoff points).

For sloping surfaces, it is necessary to determine the north or south slope before referring to the table. When the slope is known, the value found for the appropriate percentage and direction of slope is multiplied by the height of the object in order to arrive at the north shadow projection. At the same latitude, a given object will cast a longer north shadow on a north slope than it will on an equal south slope.

The examples in figure 56 show that shadow projections can be more complex than the pole example. The figures illustrate the shadow projection distances for two buildings, one oriented due south and the other southeast. The shadow projection distance marked in these examples indicates how far north other buildings must be located to avoid being shaded by each other, regardless of the building orientation or the direction and degree of slope of the site.

Analyzing shadow projections for proposed developments involves comparing shadow projections based on proposed building heights with the likely distance between buildings. Yard setbacks and street rights-of-way are added together to predict an average distance between buildings. If the shadow projection for a building of average height is greater than this distance, solar access is blocked to some extent. If the projection distance is less than the building spacing, solar access to south walls is secured.

North shadow projection distances are generally measured from the highest point of a building to the south, to the south wall of a building to the north. Where the highest building point is the roof peak, then the distances are measured from the roof peak. Where the south-lying building has a flat roof, then the distance is measured from the highest point of the roof slope. Figure 57 illustrates these measurements.

Figure 55. Generating Slopes for Shadow Projections

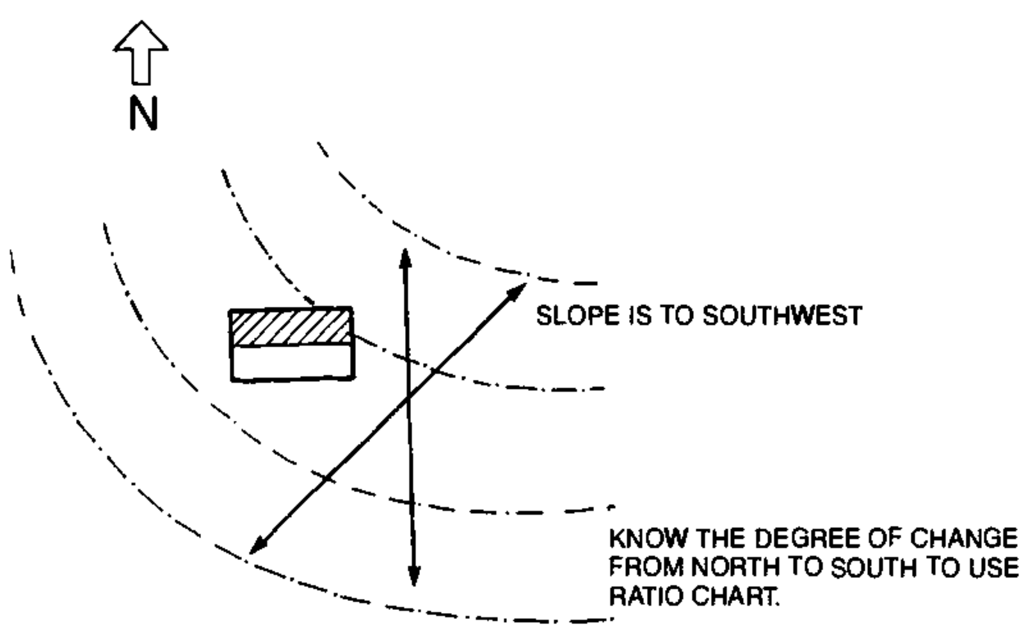
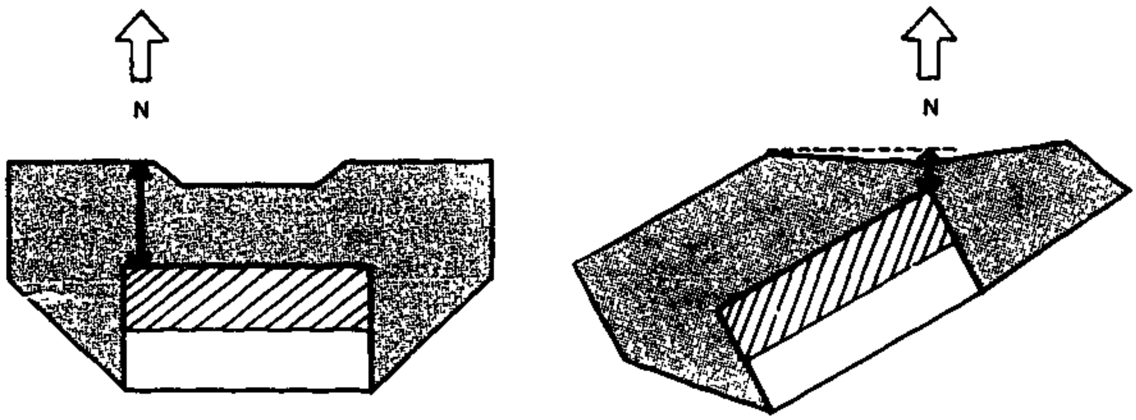
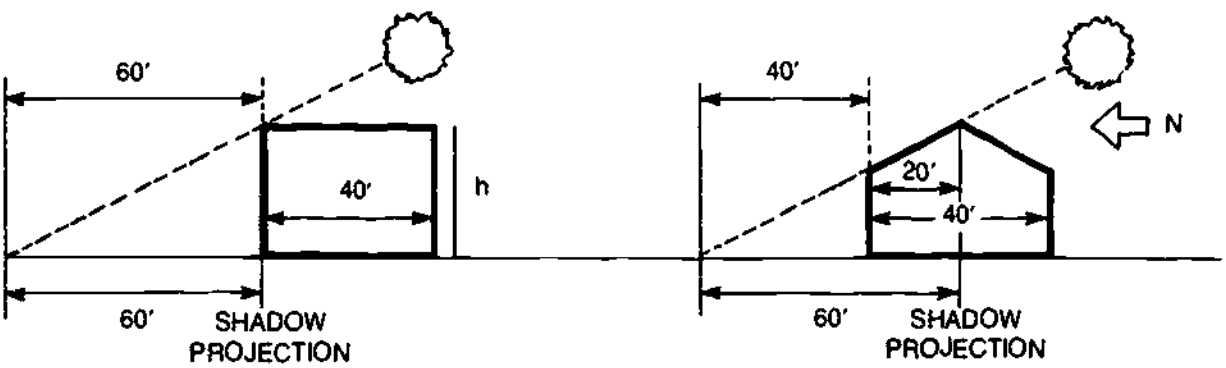


Figure 56. Shadow Projections for Two Buildings



THESE DISTANCES ARE THE NORTH PROJECTION OF THE BUILDING SHADOW.

Figure 57. Measuring North Shadow Projection for Flat and Peaked Roofs



FLAT ROOF: MEASURE FROM NORTH WALL

PEAKED ROOF: MEASURE FROM ROOF PEAK

To illustrate the use of this technique, consider a hypothetical development on a 5 percent north slope at 40 degrees north latitude. The local regulations require a 40-foot road right-of-way and 30-foot setbacks for front and rear yards. Each lot is 100 feet deep and designed along east/west streets. Each building is 40 feet deep and has a peaked roof running parallel to the building axis. The zoning ordinance allows a maximum building height of 35 feet. The developer wants to know whether buildings of this height will shade the south walls of adjacent buildings to the north.

Using the north shadow projection table in figure 54, the developer can assume that a 35-foot tall building will cast a shadow 140 feet to the north of the roof peak (4.0 x 35′ = 140). This shadow projection distance is compared to the separation distances (30′ + 40′ + 30′ = 100′) between buildings to the north and south of the roadway; see figure 58. Because the north shadow projection exceeds the separation distance, it can be assumed that the building to the north will be partially shaded by a 35-foot tall structure lying to the southeast or southwest.

To obtain south-wall access to buildings north of the roadway, it becomes necessary to reduce building heights. If the separation distance between buildings is known, building heights can be incrementally reduced until the north shadow projection distance is less than or equal to the separation distance. Figure 59 shows that a 28-foot tall building can be built without shading the south walls of buildings to the north of the roadway.

Figure 58. South-Wall Access Limited by 35-Foot Tall Building to South

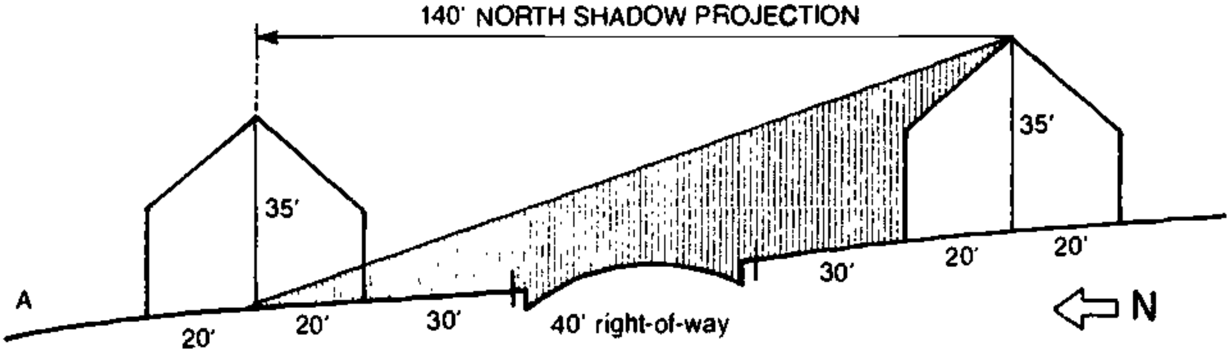
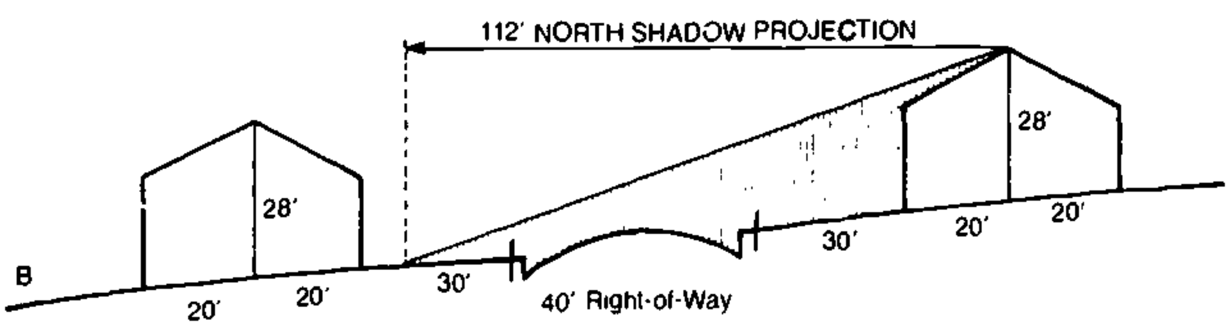


Figure 59 South-Wall Access Protected by a 28-Foot Tall Building



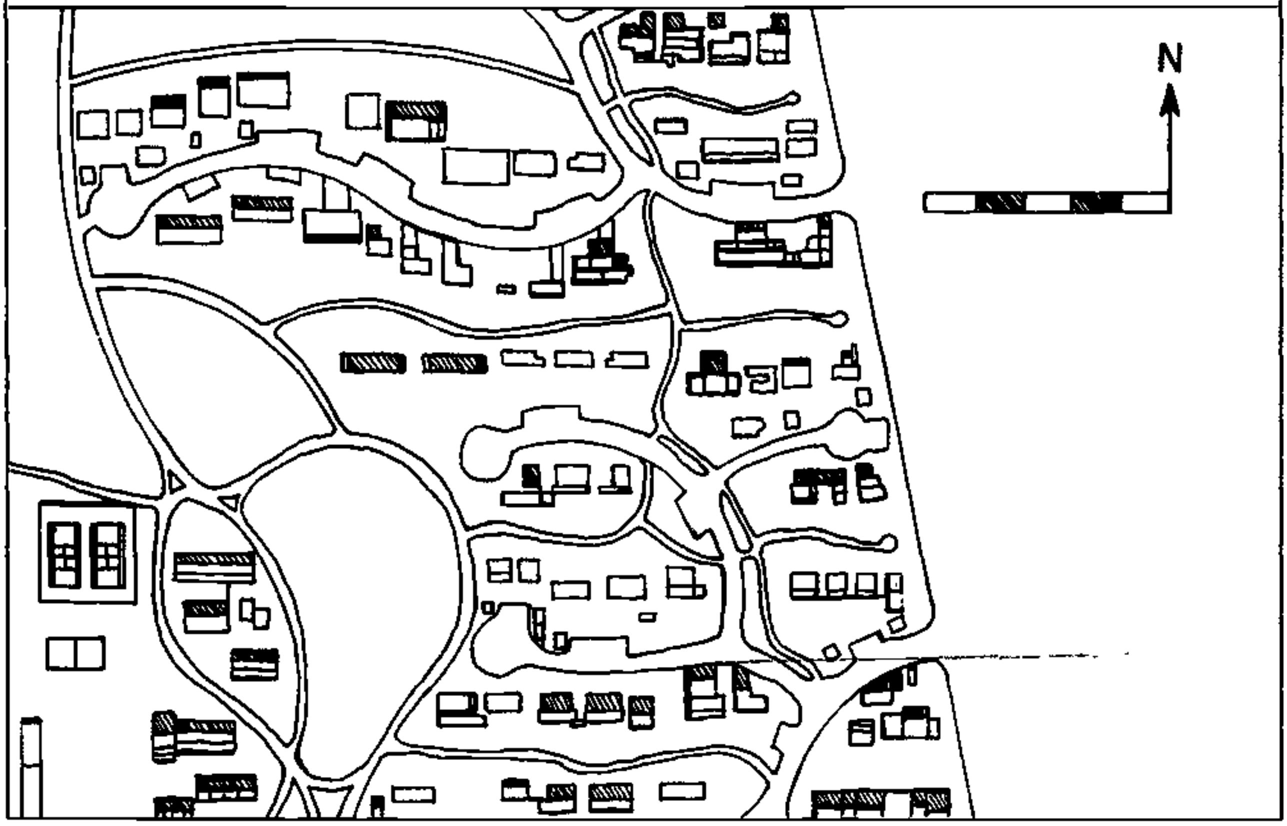
Specific Design Strategies to Protect Solar Access

Conventional site planning involves the planning of roads, lots, buildings, open space, utilities, and other public facilities within a development. Site planning for solar access adds yet another dimension to these conventional planning concerns. This chapter offers a number of alternative solar-access design strategies for each functional aspect of site planning. In some cases, the choice of strategy may be confined to only a few alternatives by local regulations or the peculiar characteristics of the site, whereas other development situations may permit several alternatives to be considered concurrently.

A note or two before getting into the specifics. First, many of the examples presume passive space heating and south-wall access. Since this is the most restrictive situation for solar energy use, if access can be protected for this use of solar energy, then it can also be protected for active space heating, natural cooling, and domestic water heating. By protecting south-wall access, a developer opens options for future solar energy use, because protecting a south wall from shading also automatically protects the south roof area.

Second, if any of the suggested strategies pose undue restrictions on other development objectives, the developer can consider changing the type of solar access. For example, if achieving south-wall access prevents the developer from meeting his density objectives, he can switch to solar technologies using rooftop access. Moreover, the developer should recognize the interrelationship of various design elements. Changing street orientation, for example, can also change lot and building orientation. The detailed site plan should be kept consistent with the development objectives presented in the preliminary site plan and site evaluation.

Figure 60. Subdivision, Davis, California



Laying Out Roads for Solar Access

The street and road system of the development is one of the major design elements of the site plan. Not only is it the single greatest construction, but it acts as the framework for lot and building layout, greatly affecting solar access to the development. In designing a road system for a new residential development, the site planner can incorporate the following solar access design strategies into the conventional design objectives of the transportation system.

East/West Street Orientation

One of the best ways to assure proper solar building orientation, especially under conventional development practices, is simply to run streets from east to west. This makes possible southern orientation of the greatest number of buildings. The technique is being used in solar subdivisions in California. Figure 60 shows a subdivision in Davis, California, with all solar-equipped homes. Most streets run from east to west, with short north/south collector streets. This development was a PUD, but even conventional developments can use a similar street layout.

Unfortunately, it is not always possible to orient streets from east to west. Topography may demand that streets follow elevation contours to minimize grading costs and to prevent erosion and runoff problems. But collectors (and buildings) still can receive adequate sunlight even if not oriented due south; that is, considerable variation from an east/west orientation is possible without severely limiting solar access to the development.

Where site constraints dictate that streets be oriented north/south, solar access can still be

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protected by reevaluating the type of solar access; for example, by using roof-mounted collectors facing south or by modifying the design of the building. In some areas of the site, however, the topographic constraints may be so overwhelming that only conventional development techniques can be used.

Orientation Guidelines for East/West Streets

Building orientation, as noted above, generally depends on street orientation. Because proper building orientation saves energy in most homes—and is absolutely crucial in homes using passive space heating—it is useful to consider regional orientation guidelines for streets in new residential development. Figure 61 divides the country into a number of geographic regions, based on shared climatic characteristics (such as temperature, humidity, and heating and cooling needs). In figure 62, an optimal street orientation is suggested for each region. The range of orientation angles from the east/west idea is only approximate, with some variation caused by such factors as topography, existing buildings, road alignments, or weather conditions (morning fog, for example). But these roadway orientation guidelines will assure proper lot layout and building orientation for solar access and energy conservation.

Of course, regional guidelines for street orientation must be used cautiously, especially for sites near regional boundaries. Nor is this the only possible way to delineate regions. As research continues on the use of climate as a design tool, other ways to categorize the various climatic regions of the country undoubtedly will be developed.

Figure 61. Regional Climate Zone Map

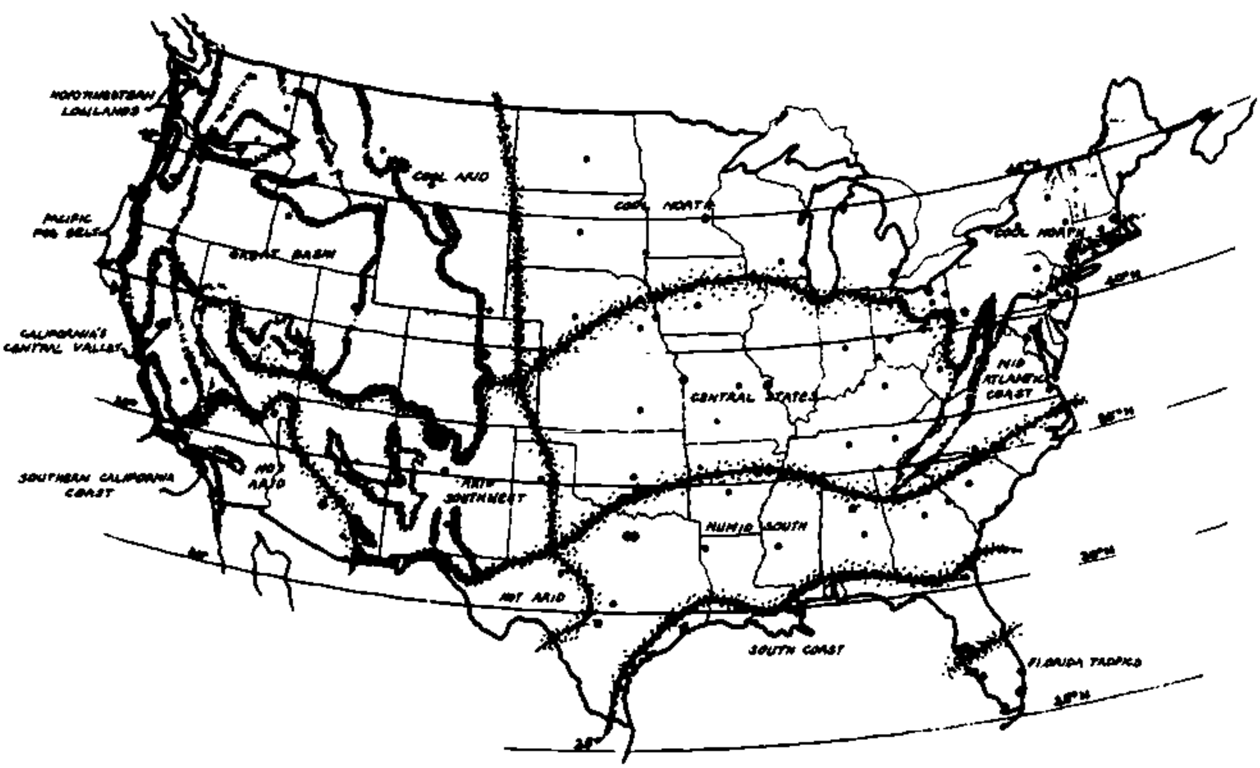
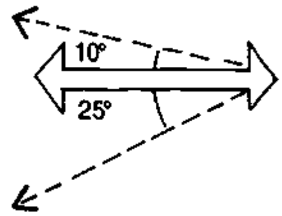
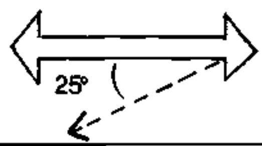
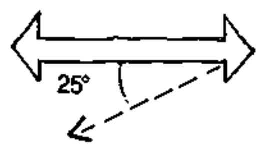
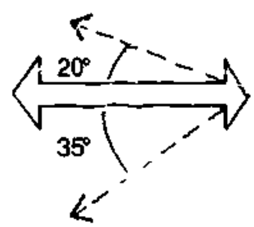
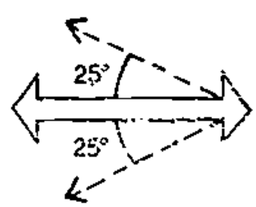
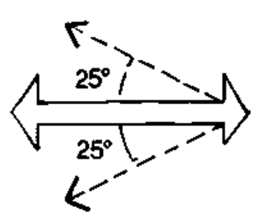
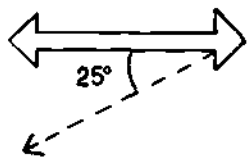
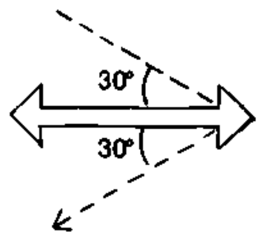
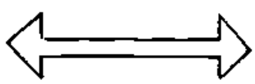
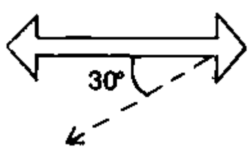
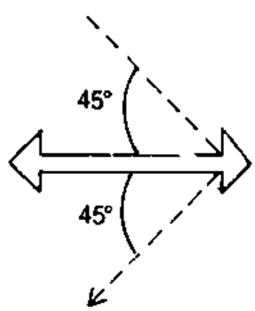
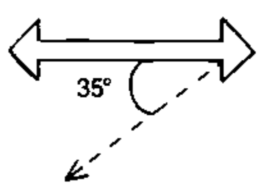
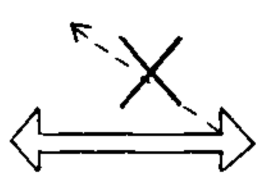


Figure 62 Suggested Street Orientations

Climate Zone		Street Orientation
Cool North		East/west with 10° variation to northwest and 25° variation to southwest.
Hot Arid		East/west with 25° variation to southwest.
Humid South		East/west with 25° variation to southwest.
South Coast		East/west with 20° variation to northwest and 35° variation to southwest.
Central States/ Mid-Atlantic Coast		East/west with 25° variation northwest and southwest. For early morning warming, a 25° variation to the southwest is preferred. A northwest variation can cause summer overheating of western windows, if not properly shaded.
Florida Tropics Natural cooling strategy		Orient buildings for maximum use of breezes. Streets should run with direction of prevailing winds.
Solar air conditioning strategy		East/west with 25° variation in either direction.

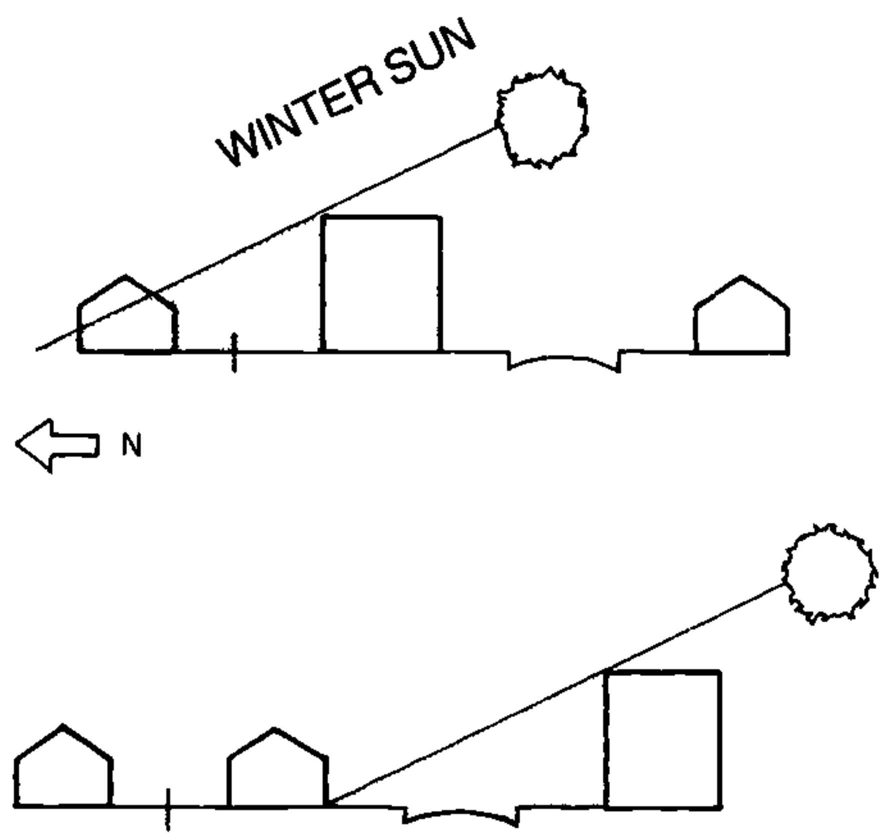
Climate Zone		Street Orientation
Northwestern Lowlands		East/west with 25° variation to southwest.
Pacific Fog Belt		East/west with 30° variation in either direction.
Cold Arid/Great Basin		East/west.
Central Valley/Arid Southwest		East/west with 30° variation to southwest.
South California Coast: Areas on coast		East/west with 45° variation in either direction.
Inland Areas	 	East/west with 35° variation to southwest. Variation to face northwest is not recommended for inland areas.

Using Street Width as Solar Access Buffers

Street width can be used to separate buildings from each other and to increase the distance between solar collectors and potential obstructions. The road right-of-way reservation required in many subdivision regulations can be modified in some situations to increase the distance between buildings on either side of the street or to increase the distance between a building and a street tree lying to the south. In developments with several housing types on east/west streets, placing taller buildings on the south side of a street and shorter buildings on the north side can help reduce shading, as figure 63 illustrates. Major streets or highways can be especially good solar buffers if they are effectively located, because they do not need solar access. To use roads this way is better than using valuable open space as a solar buffer.

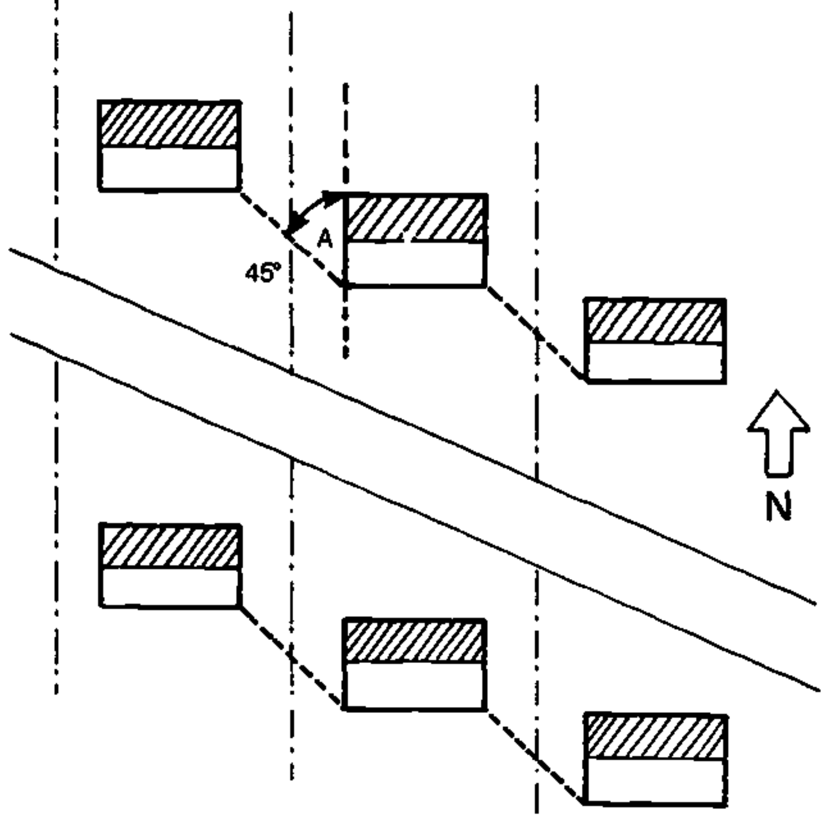
Using streets as solar access buffers is not appropriate in northern latitudes, where sun angles are low and shadows are long. Narrower street width standards are more appropriate in southern climates, where the emphasis should be on ways to minimize pavement heating by the hot summer sun and to allow more effective shading of streets by street trees. Of course, present and

Figure 63. Street as Shadow Buffers



7.3

Figure 64. Lot Orientation on Intercardinal Streets



Maintaining south orientation of housing where streets are shifted from the east/west axis. Angle A is formed by the intersection of north/south with a line connecting the southwest corner of one house to the southeast corner of its western neighbor.

future traffic load and circulation objectives must also be considered, as must be the requirements of local regulations for non-PUD developments.

Lot Design Strategies for Solar Access

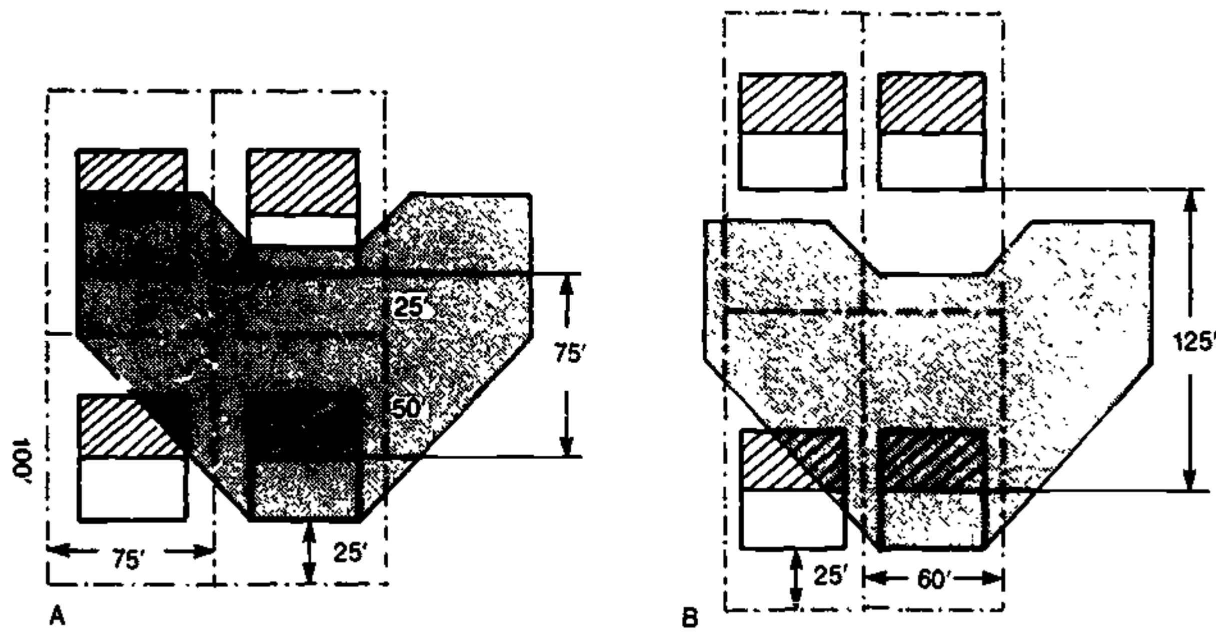
In most conventional single-family developments, the long axis of each lot is perpendicular to the street, while the long axis of the home is parallel to the street. In most townhouse developments, both the long axis of the building and the long axis of the lot are perpendicular to the street. In designing a project for solar access, the developer wants each building to be oriented to the south, that is, with its long axis running east/west. He can design the development with the streets oriented from east to west, so that the lots and buildings also are oriented east to west. Or he can ignore the street orientation and orient each lot with long axis running north/south, so that conventionally sited buildings are oriented to the south.

Lot Orientation on East/West Streets

The corollary to east/west street orientation is north/south orientation of the long axis of lots. When it is not possible to run streets from east to west, lots still can be platted so that they have proper solar orientation. If streets must run from the northwest to the southeast, for example, then lot lines can be laid out at oblique angles to the street, as pictured in figure 64. The diagram shows the long axis of the lots running from north to south, making it relatively easy to site the houses for maximum solar orientation. Note: Angle A (shown in figure 64) must be 45 degrees or greater to prevent the south walls of the houses from being shaded by their neighbors.

Figure 65. Reducing Frontage

By reducing frontage from 75' to 60', plan can accommodate 112' north shadow projection cast by 28'-high buildings.



Reducing Lot Frontage on East/West Streets

Reducing the frontage of lots on east/west streets is one way to improve solar access. Keeping lot size constant while reducing frontage results in lots that are narrower from east to west and longer from north to south, with more distance between buildings from north to south. Thus, better solar access. Figure 65 illustrates how this works. The example is based on conditions of 40 degrees north latitude, a five-percent north slope, a 25-foot front yard, and 28-foot tall buildings. In Case A, with 75 feet of frontage, the north shadow projection falls on the more northerly building. By reducing the frontage to 60 feet and lengthening the lot, as in Case B, a 112-foot north shadow projection can be accommodated. Obviously, this option means a reduction of side yard space and gives a development a more clustered look.

For lots located on streets that are not oriented east to west, changing frontage does not necessarily improve solar access. To improve solar access for buildings on a north/south street, the frontage would have to be increased to such an extent that the result would be short, wide lots with large frontages. Such lots cost more for streets and utilities and have less yard privacy than conventional lots. An exception could be made for multifamily townhouse development with long, narrow buildings and lots. (See the following section on multifamily development.)

On angular or intercardinal streets, changing the frontage is again of limited value. For houses on such streets, morning or afternoon shading is the real problem. Reducing frontage only makes the situation worse. In some cases, though, slight increases in frontage could improve solar access by providing a greater buffer against morning or afternoon shading. Whether a change in frontage improves solar access in these cases depends on the specifics of the site.

Changing frontage to promote solar access in multifamily housing depends on the type of multifamily units. For duplexes, reducing the frontage on east/west streets improves solar access by deepening the lots, provided that the long axis of the duplex parallels the street. The situation is nearly the same as for the single-family houses shown in figure 65.

For townhouses or apartment buildings, reducing frontage is a less useful tool for protecting solar access. Townhouses (and apartments) usually are not subject to frontage requirements but are governed by such requirements as floor area ratios. Even when such developments must meet a frontage requirement, it is often impossible to improve solar access by changing frontage.

Lot Layout on North/South Streets

When streets cannot be oriented from east to west, even on a diagonal, siting buildings for proper solar orientation becomes more of a challenge. There are two ways to maintain proper lot orientation on north/south streets: by combining lots and by using "flag" lots.

Combining lots is especially useful where the lot layout has already been dictated. Two lots that abut each other on the north or south can be replatted; the buildings lying close to each other in an east/west orientation provide maximum solar access, as figure 66 illustrates. The technique calls for a departure from conventional single-family, detached housing design. The houses pictured are duplexes, although it would be possible to use detached units in a similar way. The developer must consider whether the added benefit of proper solar orientation balances any market desire for more traditional building siting.

Figure 66. Combining Lots for Proper Orientation

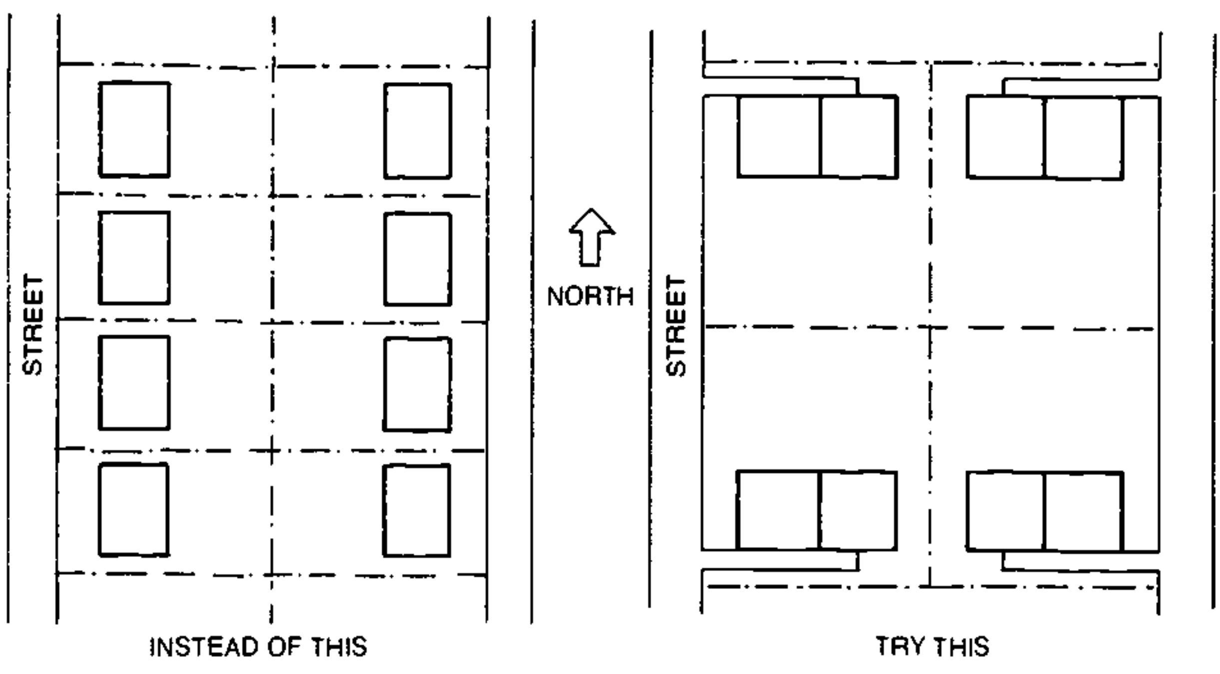


Figure 67. Using Flag Lots for Proper Orientation on North/South Streets

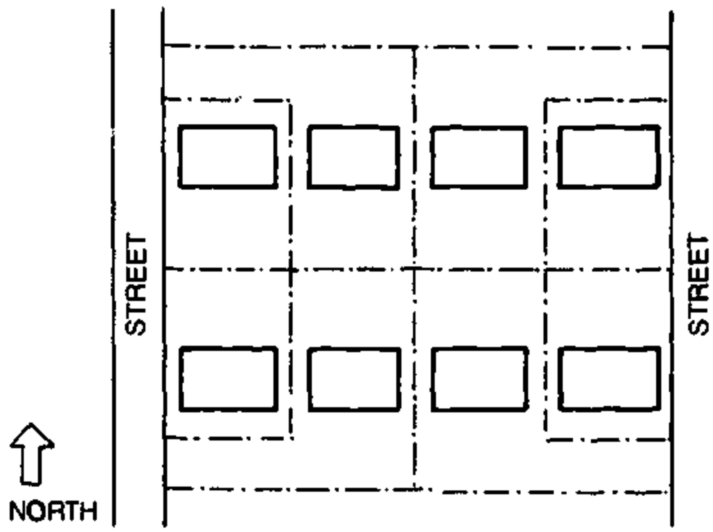


Figure 68. Mobile Home Orientation on North/South Streets

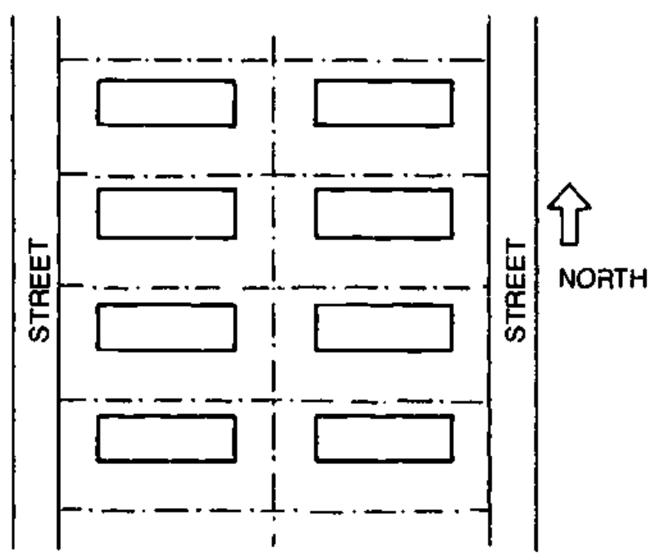
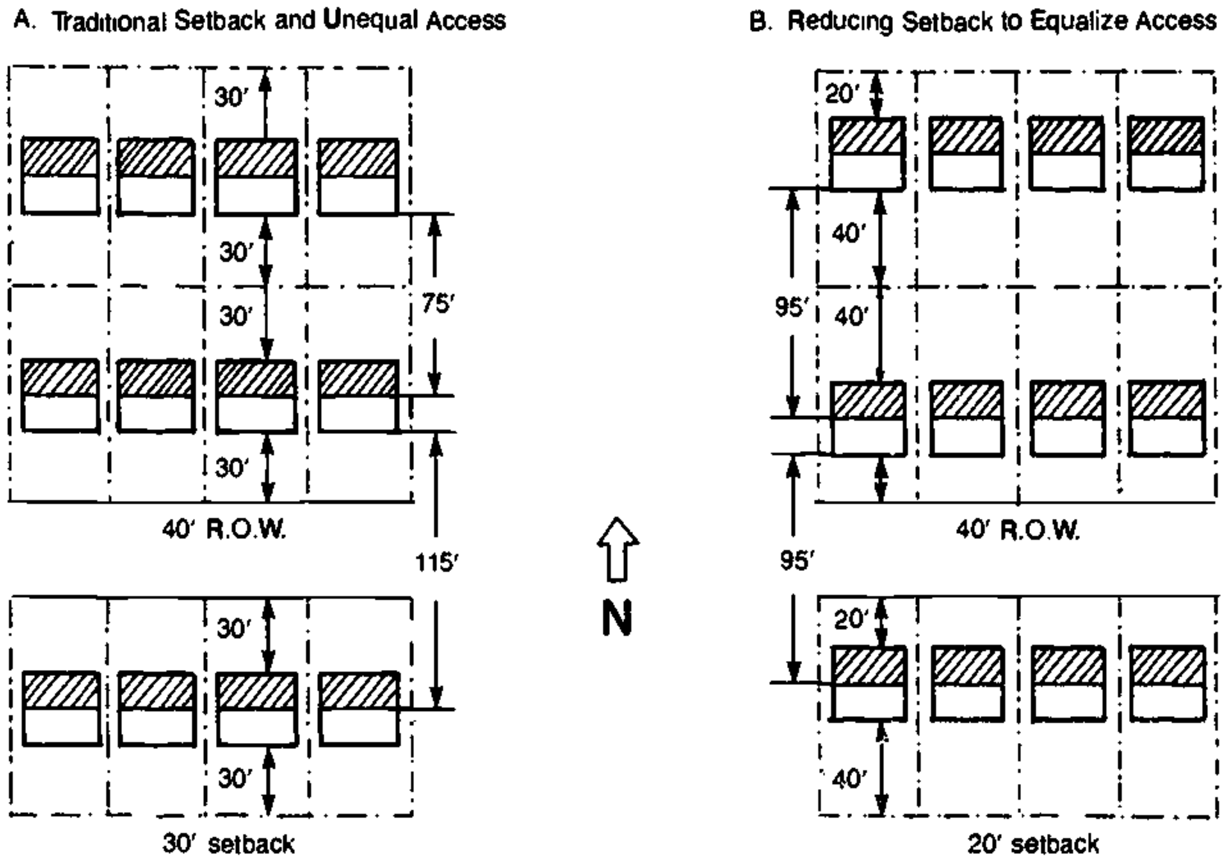


Figure 69. Reducing Setback to Equalize Access



Hypothetical site, flat at 40°N. latitude, with a shadow projection of 87.5′ for 25′-high buildings.

In A, only buildings to the North of road right-of-way have south-wall access. By reducing setback by 10′ (from 30′ to 20′), all structures have south-wall access in B. This affects shading only by buildings; street trees must be regulated to prevent shading problems.

The flag lot technique is used when the streets are spaced so far apart that four lots can be run in an east/west direction, with the "pole" of the flag connecting the inner lots to the street. Figure 67 shows how. This technique is unconventiona' and might not be allowed under local regulations. Although it may result in higher utility connection costs for the inner lots, it does have the benefit of creating conventional spacing between the ends of buildings.

Where buildings are fairly short, as in mobile home developments, it is possible to have good solar access even on north/south streets. See figure 68.

Siting Strategies for Single-Family Detached Housing

Along with site planning for streets, planning for solar access requires consideration of the siting of buildings. The discussion of building siting begins with single-family detached housing.

Equalizing Solar Access

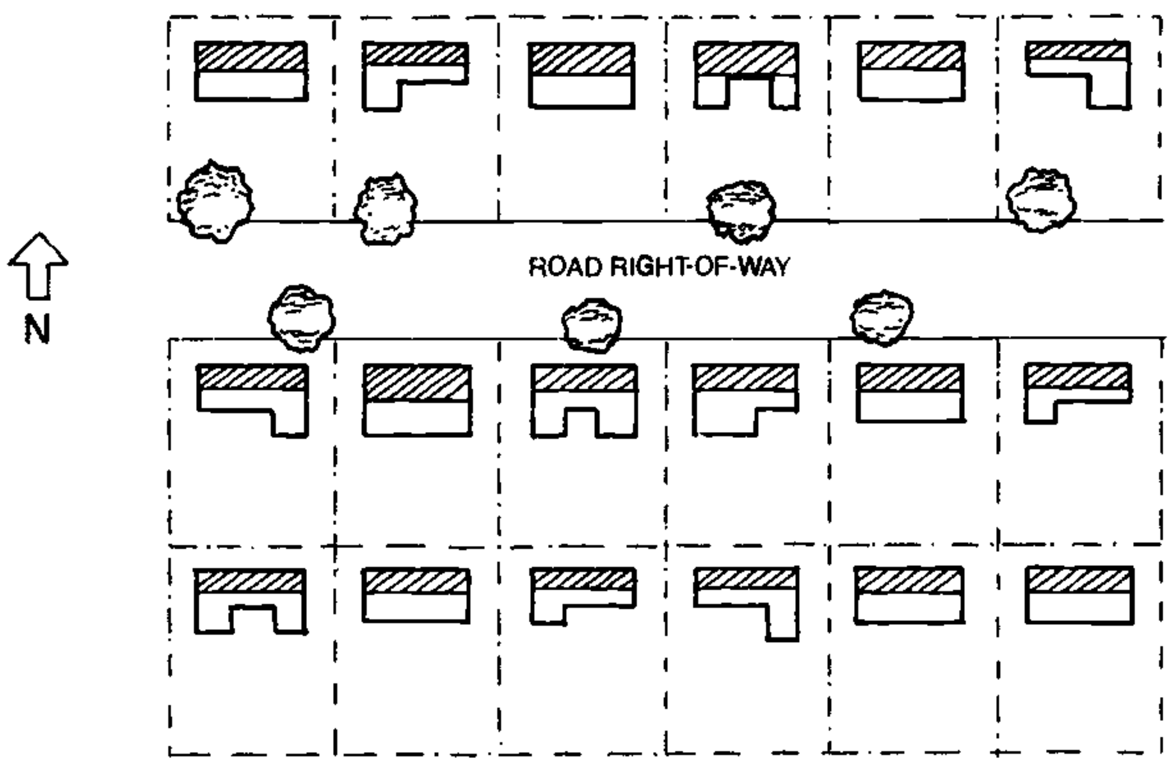
In developments where buildings are sited in the traditional way with front, side, and rear yards, some buildings usually have better solar access than others. As figure 69A shows, in higher density districts the rear yards of buildings sited on east/west streets may be relatively small. As a result, the distance between houses that back on each other (in the illustration, 75 feet) is less than the distance between houses that face each other (115 feet). Consequently houses on the south side of the street are shaded.

But it is not always necessary to change the zoning provisions to improve solar access for the shaded buildings. Depending on latitude and topography, adequate solar access may be provided under standard setback requirements by means of a simple adjustment. By reducing the front yard setback and increasing the rear yard setback, the distance between houses that back on each other and houses that face each other can be made nearly equal. In effect, this moves all the structures closer to the street and improves solar access to the houses on the south side of the street—as figure 69B illustrates.

The precise change in yard space depends on the latitude, the topography, and the orientation of the structures. Generally, this technique is most effective on east/west streets, although it may also work on diagonal streets. Lots and houses on streets oriented from north to south would not gain anything from this strategy, because the streets do not offer any additional buffer from shading.

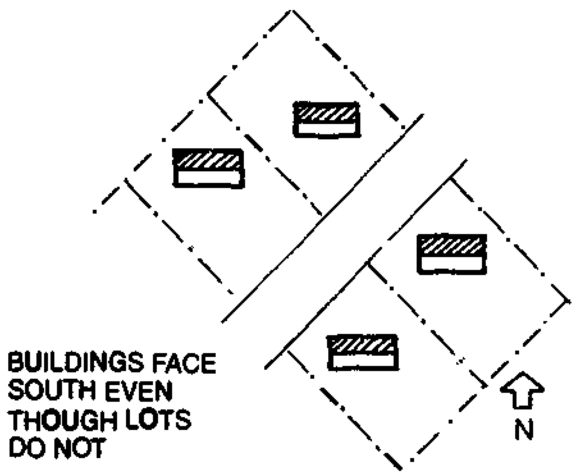
This remedy works only for shading by adjacent buildings, not by street trees. Unless vegetation is carefully selected and sited, moving houses nearer to the roadway could mean that the houses and their collectors would be shaded by the street trees—actually decreasing rather than increasing solar access. This strategy should, therefore, be considered only when vegetation is strictly controlled according to the design strategies discussed in Trees and Landscaping.

Figure 70. North Zero Lot Line Siting



ALL BUILDINGS ARE SITED AT NORTH LOT LINE.

Figure 71. South Building-Orientation



Zero Lot Line Strategies for Solar Access

One design option that is particularly useful for protecting solar access in any development is a variation of zero lot line siting, an innovative technique in which buildings are sited so that they abut property lines. For solar access, allowing buildings to abut the *north* lot lines provides the greatest possible yard area to the south of each building. Figure 70 shows how this works.

Siting buildings this way gives each homeowner maximum control over the placement and size of accessory buildings and trees. It has the added benefit of increasing the distance from trees and buildings on adjacent lots, which usually are not under the control of the homeowner. This increased distance is especially valuable if shading by street trees is a problem. The distance between buildings is essentially the same whether a zero lot line or traditional setback approach is taken, but the distance from trees along the street is increased—especially for buildings on the north side of the street. It also means that the owner has greater personal control over the buffer area between his building and buildings and trees to the south.

This technique is equally applicable to houses and lots on east/west or north/south streets. The zero lot line technique may also be useful if lots are large enough on north/south streets and buildings are sited with their sides to the street for maximum solar orientation.

The zero north lot line technique may also be useful for lots and buildings on diagonal streets Applied to lots on a street that run from northeast to northwest to southeast, the provisions allow for siting the building in the northernmost corner of the lot; one or two of the corners of the building will touch the northeast or northwest lot lines, as figure 71 illustrates. In this situation, there still may be substantial shading from adjacent buildings in the morning and afternoon.

In most cases, the zero lot line technique should be applied to every building and lot in a project. Otherwise, there could be significant shading, especially for lots and houses on east/west or north/south streets. If one building is sited on the north lot line and another building is sited in the center of the adjacent lot, the latter building may substantially block the south-wall solar access of the first building in the morning or afternoon hours.

The use of this technique may involve some tradeoffs with other development objectives. First, the application of this technique can significantly change the design of residential neighborhoods. Houses to the south of an east/west street would front the road, while buildings to the north would be set back a greater distance than might be the norm for the community. This unusual massing of structures along both sides of a street is, however, likely to be more an apparent than an actual tradeoff. In such subdivisions a sense of visual balance is maintained by homeowners on the nortn side of the street installing privacy fences and garages along the street front. The apparent mass of these structures appears to balance the visual mass of the homes close to the road on the south side of the street.

A second drawback is that utility connections might be more expensive for the lots on the north side of the street, because they are farther from the utility easement within the road right-of-way. This cost is balanced, however, by the savings for utility hookups to houses on the south side of the street.

Finally, moving houses so close to the street may limit the occupants' privacy. Privacy may be preserved, however, by putting in fences or landscaping to shield the house from public view.

Uniform Setback Requirements for Solar Access Protection

Under traditional setback practices, buildings in a development may be staggered in distance from the street or real lot line to meet minimum yard requirements. This can pose a shading problem in the morning or afternoon. Uniform building setback, on the other hand, protects solar access. If all the south building walls line up (or nearly line up), the buildings cannot shade each other. Figure 72 illustrates the solar access benefits of uniform setbacks over staggered setbacks. Remember, too, that the minimum 45-degree setback angle is always measured from the north/south axis, as shown in figure 73.

Placement of Garages, Carports, and Fences

The site planner must also plan garages, fences, and other accessory structures so that they do not shade the south walls of buildings requiring solar access. The principle is simple. Accessory structures can be sited to the north of the main building whenever possible, if they do not cause a problem on adjacent, northerly property. When garages or fences are sited to the south, they must be set far enough back from the main building that their shadows do not encroach on the collector's skyspace. Siting them as close as possible to the southern property line is desirable for this reason. Figure 74 shows how this works.

When zoning regulations require setbacks for fences or carports, it is sometimes necessary to negotiate with public officials for permission to site these structures for good solar access. (The companion guidebook on regulations can be helpful in such an effort.)

Figure 72. Uniform versus Staggered Setbacks

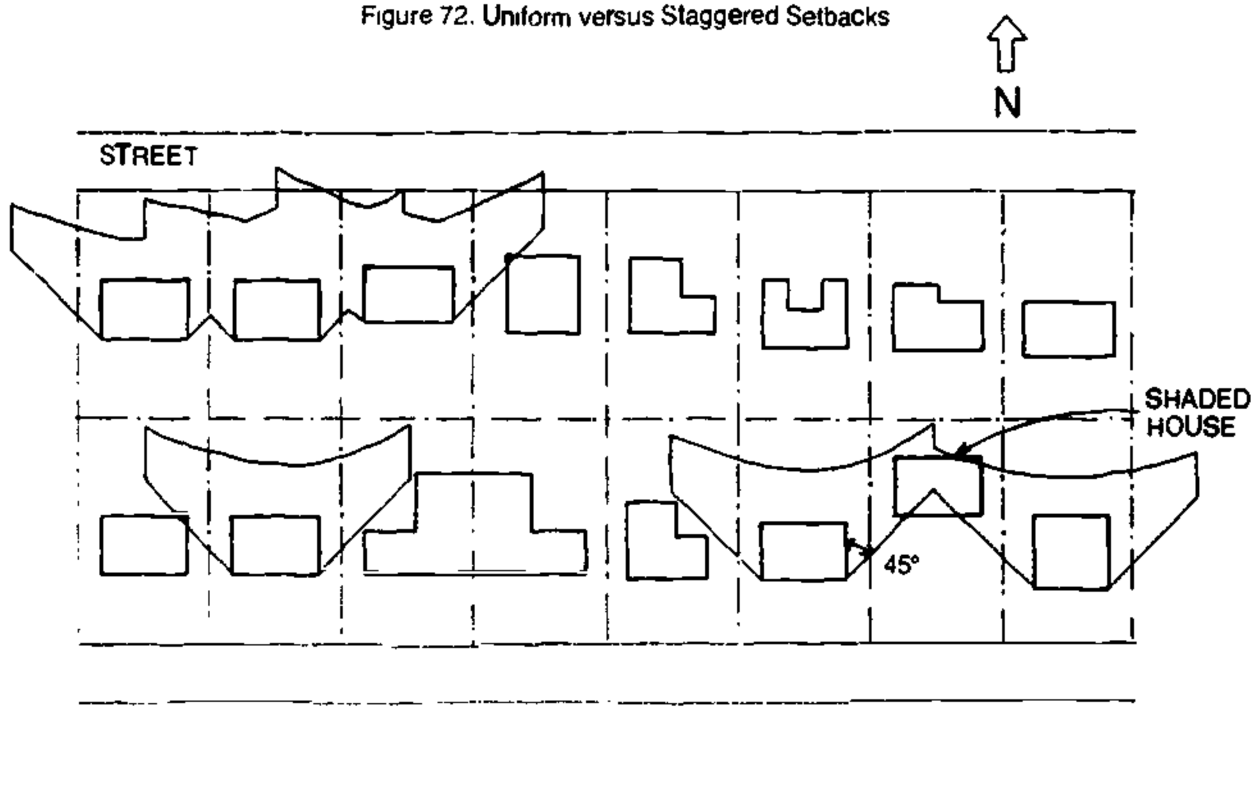
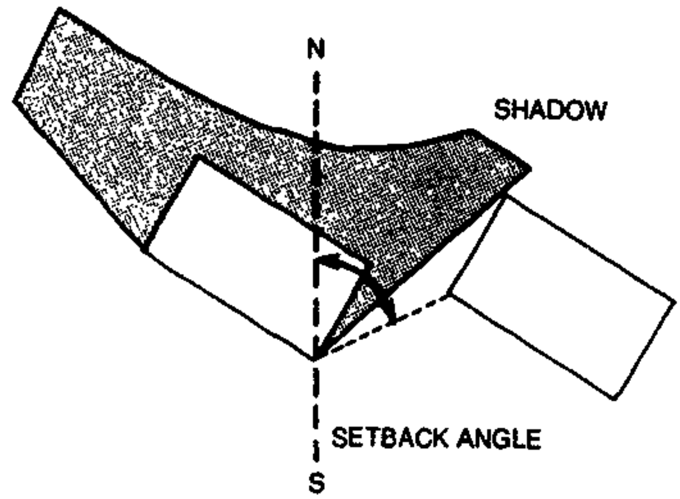


Figure 73. Measuring Setback Angles

PLAN VIEW OF TWO BUILDINGS



MEASURE SETBACK ANGLE FROM THE NORTH/SOUTH AXIS.

Figure 74. Placement of Garages

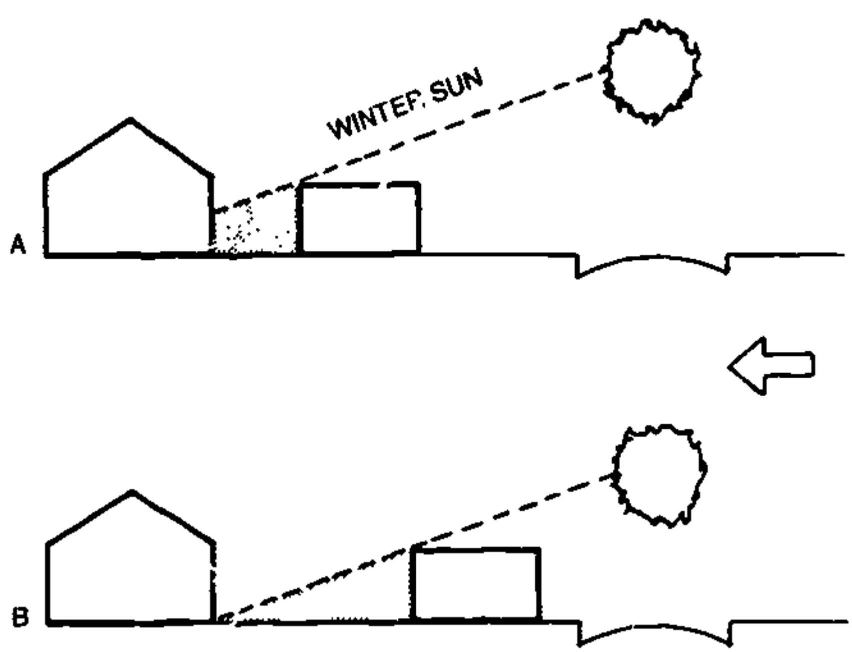
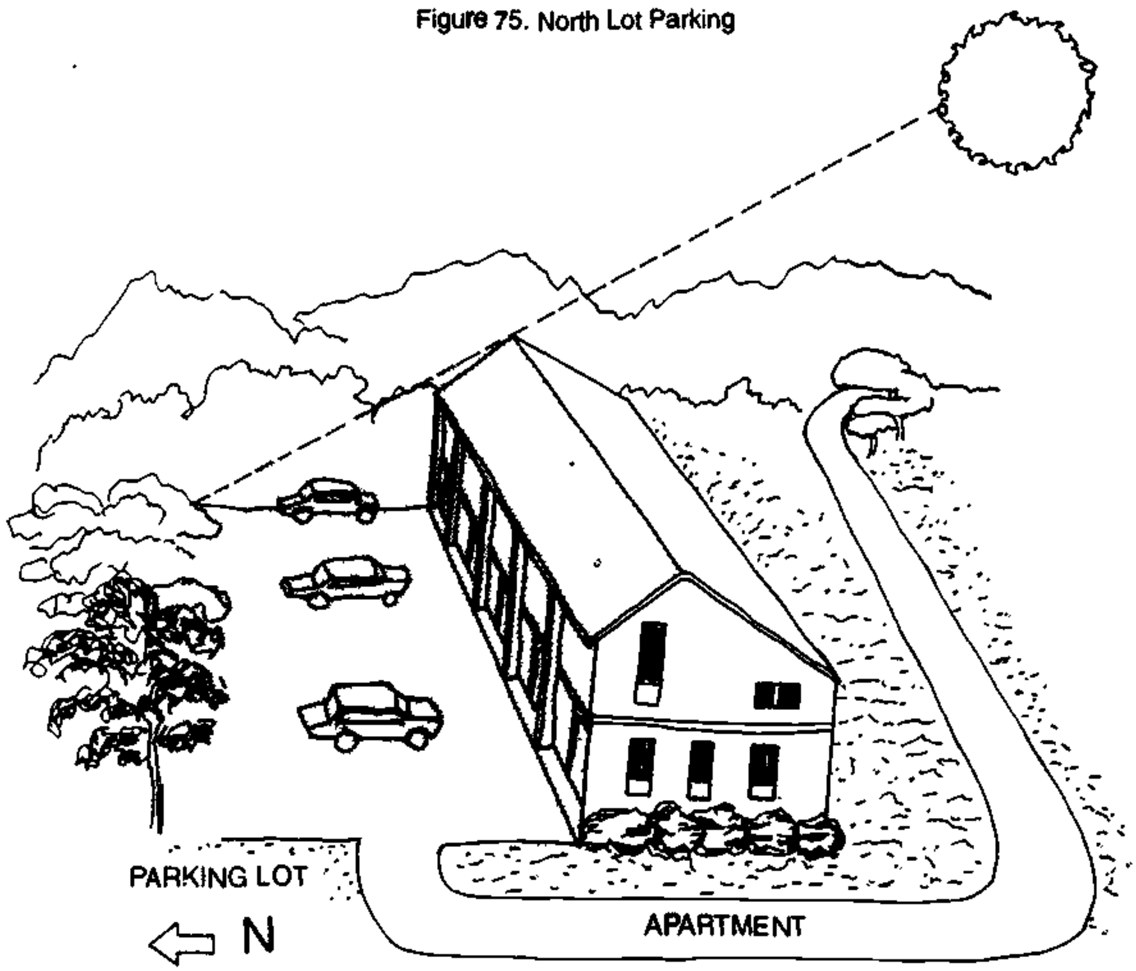


Figure 75. North Lot Parking



Siting Strategies for Low-Rise Multifamily Housing

Low-rise multifamily housing includes all attached structures fewer than four stories—duplexes, quadruplexes, townhouses, rowhouses, and multistory flats. As suggested in the chapter on design approaches, these structures provide special opportunities for site planning: because they frequently cover a great deal of land, they offer the site planner more flexibility in locating accessory uses in a way that protects the solar access of the main structure. In many cases, though, the same techniques for single-family detached housing are equally appropriate for low-rise, multifamily buildings.

Applying Siting Techniques from Single-Family to Multifamily Housing

The siting strategies for maximizing solar access to single-family developments—east/west street orientation, zero lot lines, and uniform setback requirements—can also be used for multifamily developments. In some respect, the latter are more flexible than single-family projects because of their greater reliance on active solar collectors. Active collectors can be roof-mounted, ground-mounted, or mounted on the roof of an accessory building (such as a carport) and, therefore, do not require south-wall access. Moreover, the generally greater height of multifamily buildings raises collector surfaces above most obstructions.

Modifying setbacks to maximize solar access can be particularly useful for duplex units sited in the same way as single-family homes. The modification can be used to improve south-wall access for the duplex units and prevent unequal solar access caused by small rear yards. With townhouse units, the approach is less appropriate. Usually the ends of the townhouse units face the streets or the backyard, so any change in setback improves access to only one of the narrow walls of the building, which is no great boon to solar energy collection. In any case, townhouses are likely to use rooftop collectors, which are not affected by a change in setback.

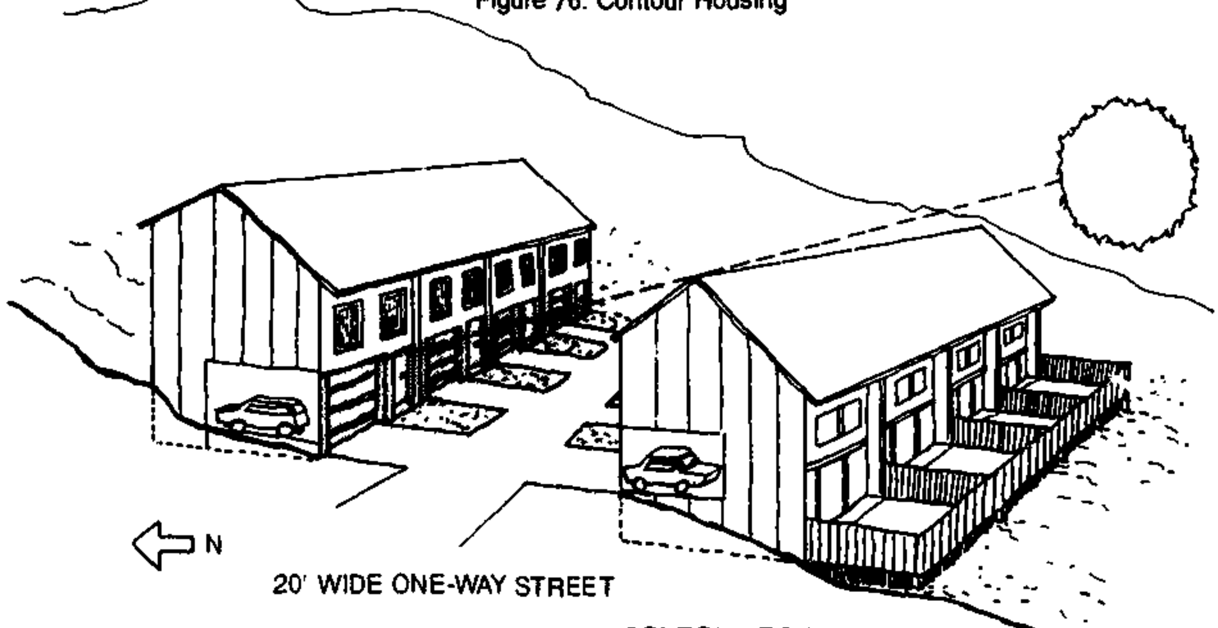
The zero lot line approach can be used for all varieties of multifamily housing to improve solar access. Whether the units are individual duplexes or large apartment buildings, siting the building on the north lot line improves the control over shading caused by nearby buildings. Larger multifamily developments are usually subject to flexible setback, lot coverage, or perimeter requirements rather than traditional yard requirements, and any code provisions that address the siting of such projects should be made flexible enough to permit zero lot lines.

Uniform setbacks are useful for all types of multifamily housing if south-facing buildings line up with each other and any shading from east and west buildings is kept outside the setback angle. If zoning provisions for multifamily districts are flexible, then a specification for uniform south-wall setbacks may not be necessary.

Site Planning Multifamily Housing as Large-Area Uses

In addition to the techniques used for single-family housing, low-rise multifamily housing can benefit from special techniques that solve its unique problems. Automobile parking, for example, is a much more important consideration in multifamily developments than in single-family projects. But it can be an asset. For example, a parking lot sited to the south of a structure can be used to create a shadow buffer. Alternatively, the unbroken

Figure 76. Contour Housing



shadow belt that a long row of two- or three-story rowhouses casts to the north makes an ideal location for roads and car parking. (See figure 75.)

Low-rise multifamily housing can also be sited to take advantage of slopes that increase insolation and solar access. Special techniques can be applied in these situations, but the cost of grading and cut-and-fill development has to be considered. Row housing is well suited to south slopes up to 20 percent, provided that the structures parallel the contour. At low latitudes, gentle north slopes can also provide good solar access. On very steep sites, consider long blocks of buildings backed into the hillside along the contour and paralleled by one-way access roads, as figure 76 illustrates.

Except on south slopes, contour development is not recommended as a way to increase solar access. It requires too much grading and site preparation to justify the cost. Stepped construction that uses cut-and-fill site preparation (as shown in figure 77) also improves solar access, but it, too, is both costly and likely to produce erosion or sedimentation problems.

Siting Strategies for High-Rise Housing

Tall buildings cast big shadows, and they are generally located near other tall buildings. In such situations, it is crucial to draw the shadow patterns of adjacent buildings in cross-section, so that the building can be planned with its lower floor having

Figure 77. Stepped Construction on West Slopes

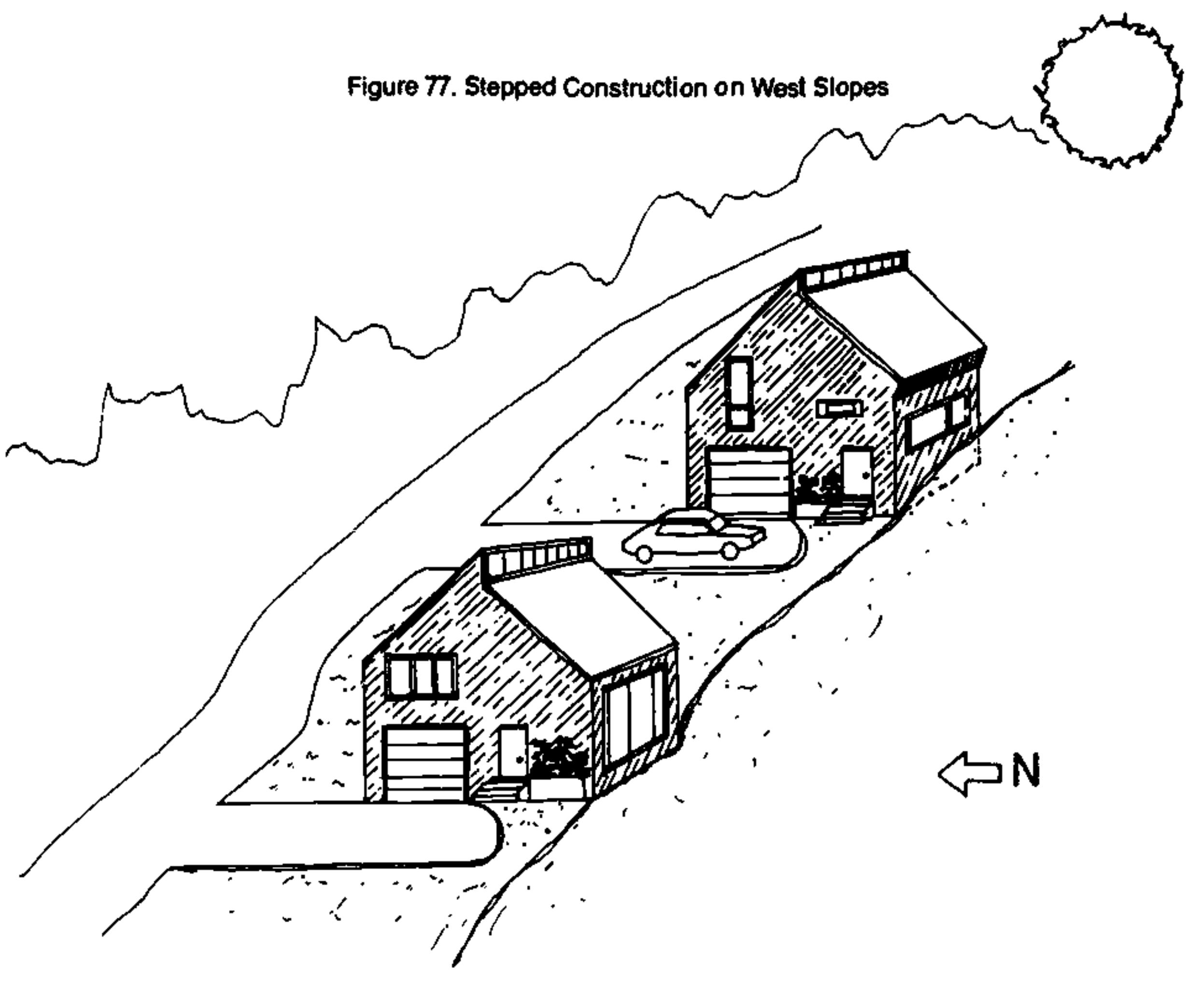
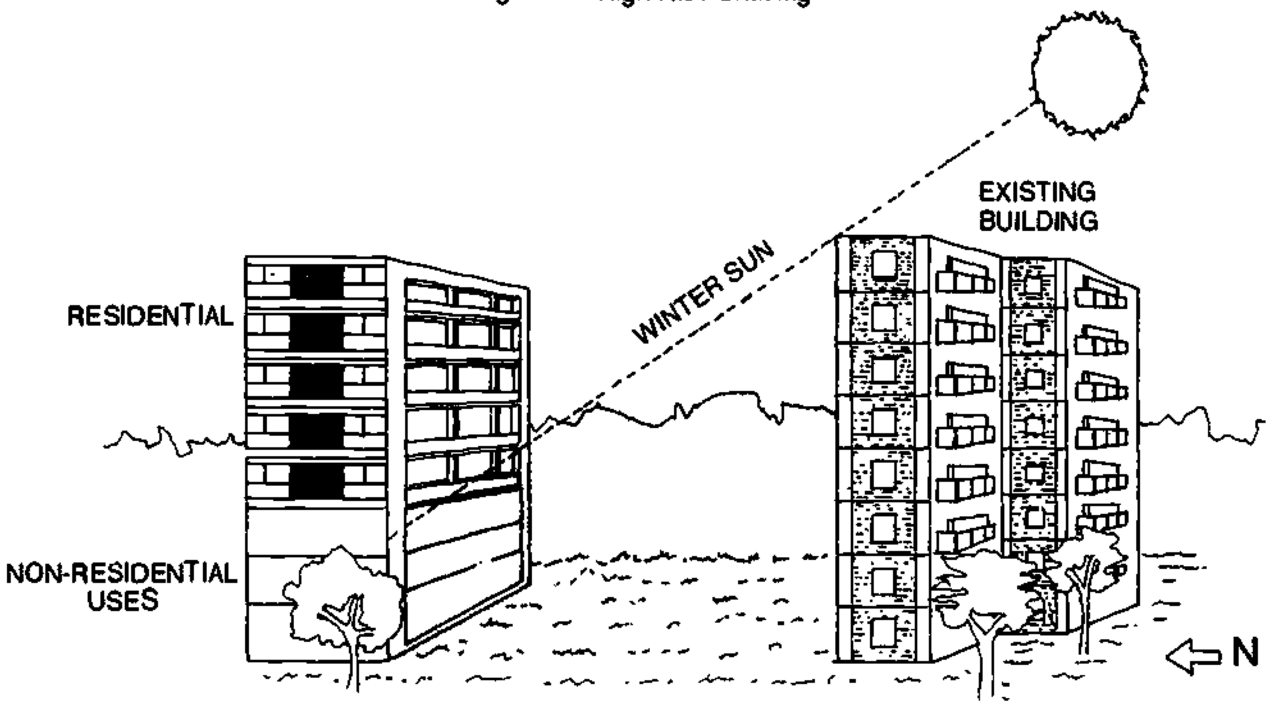


Figure 78. High-Rise Shading



In urban sites, draw shadows of adjacent buildings in section to see what part of the new building will be shaded.

limited solar access. These floors can be used for nonresidential uses, such as parking, as shown in figure 78.

Planning Open Space for Solar Access

In larger projects, most developers are required to provide open space for recreational or environmental purposes and a growing number are doing so voluntarily. Developers and site planners can use the strategic location of open space and buffer strips to protect solar access.

Using Open Space as a Solar Access Buffer

When a project—a mixed-use development, for example—is to contain some relatively tall buildings, open space can be located to the north of the tallest buildings to buffer shorter buildings to the north against the tall building's shadow. See figure 79.

The problem is that open space used for parks or recreation needs sunlight. Using such space to buffer buildings from shadows means that play areas would be shaded for much of the day. In colder climates, this would mean shortening the period of the park's usefulness. The problem must be considered on a case-by-case basis. If the open space is heavily wooded, for example, the shading is less of a problem, since the trees provide some shading too. Or, if the taller buildings are only three or four stories high, then a narrow buffer strip would be sufficient to prevent shading and open more park land for maximum sunlight. Only high-rise buildings create a significant problem here.

Figure 79. Open Space as a Buffer

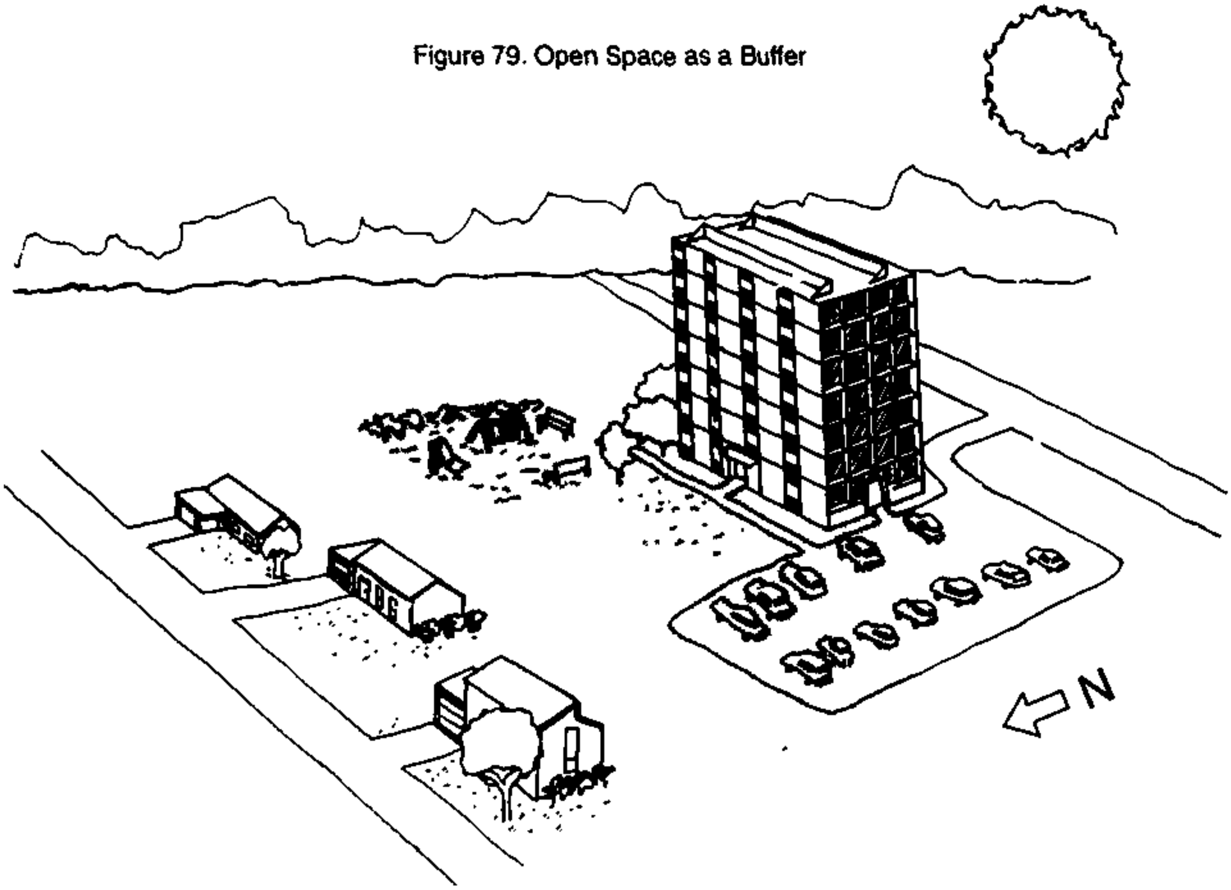
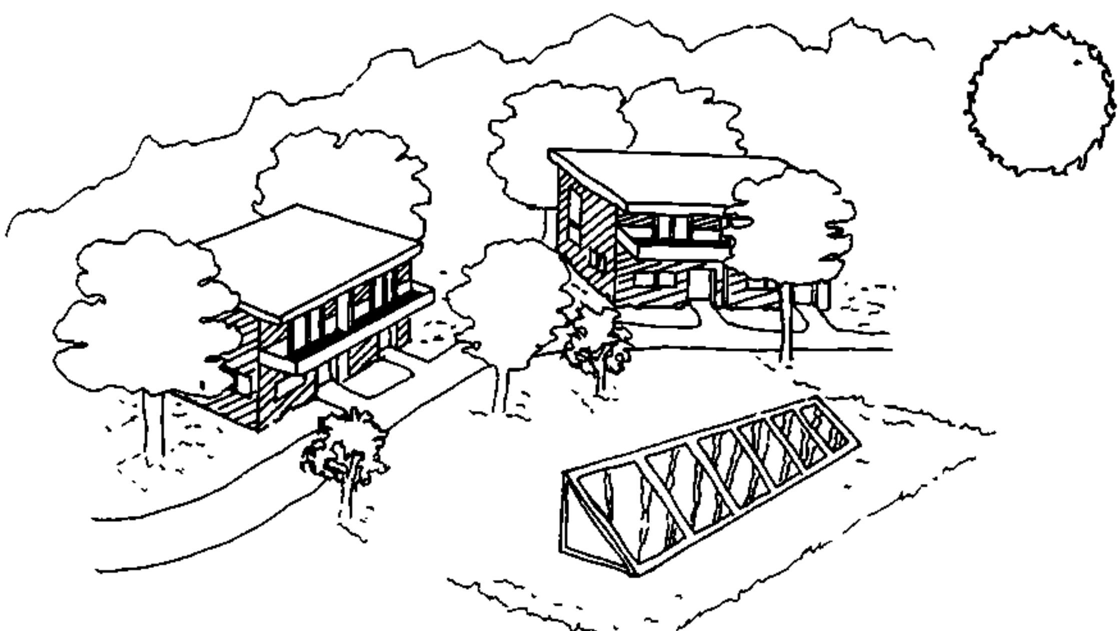


Figure 80. Common Collector Bank



Using Open Space as the Location for Central Collectors

When rooftops, south walls, or other building locations cannot be used, open space can be used as a site for common solar energy collectors, a bank of active solar collectors servicing the buildings in a development. Of course, the open space has to have unobstructed access to sunlight. The heat would be collected in the common collector system and transferred to the buildings. Buildings adjacent to the collector area would have to be sufficiently distant to prevent shading of the collectors, yet close enough to the collectors to minimize heat loss during the transfer of the heated water or air to its point of use. (See figure 80.)

A common collector system is probably most appropriate for multifamily projects, where the roof might be able to provide only enough collector area to heat water, whereas a detached collector in nearby open space can provide space heating as well. The type of solar energy system to be used and the size of the collector depend on a number of factors, including the local climate and whether the multifamily structures can use passive solar heating.

Trees and Landscaping

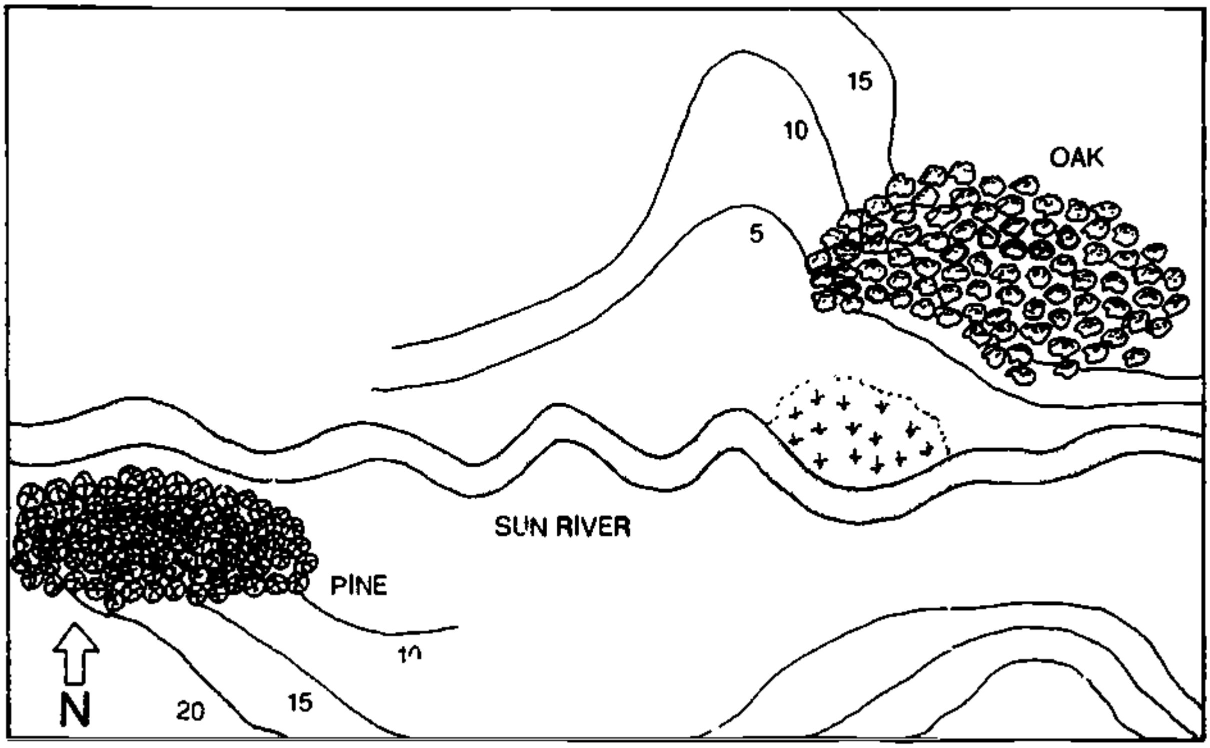
To protect solar access, it is more difficult to plan for trees than for buildings. Shading characteristics change from species to species, from season to season, and from year to year. Many developers include landscaping in their plans, but generally the primary concern of landscaping plans is aesthetic. For solar access planning, though, it is necessary to give as much attention to trees as to the other components of the development. They have an effect not only on solar access but also on the energy efficiency of the development. Trees and other vegetation can reduce cooling needs in summer by shading and reduce heating needs in winter by acting as windbreaks. These reductions, in turn, make it easier for a solar energy system to compete with conventional methods of space conditioning.

This chapter discusses three topics: existing vegetation, planning new trees that are part of a project landscaping plan, and tree maintenance. Because vegetation is so specific to a region's climate and to a site's characteristics, it is difficult to provide a detailed discussion on the management of vegetation for solar access protection. The chapter presents some basic guidelines that must be used as the developer or site planner proceeds with a project.

Solar Access and Existing Vegetation

One of the most difficult tradeoffs in planning for solar access involves the presence of trees on a site to be developed with solar homes. In many cases there is simply no way to avoid taking down at least some trees to provide access to south walls and rooftops. Sometimes the preservation of trees is required by law, and the developer has to contend with local officials to protect solar access.

Figure 81. Vegetation Types Analyzed on Base Map



The presence of trees on a site forces the developer to answer some important questions: How heavily forested is the site? How many trees might have to come down? Are there areas that could be used for central collectors? What tree species are present? Will they let in enough light in the winter? Can some trees be just trimmed or topped? The developer also has to decide which is the stronger selling point, solar access or a nice canopy of trees. Perhaps some compromise can be reached, so that some buildings can be given solar access while the most valuable or beautiful stands of trees are preserved.

The planning problems caused by existing trees may be eased in several ways. First, analysis of the site prior to planning the development may show certain areas to be freer of trees than others. If such areas happen also to be on south slopes, then they clearly are suited for placement of solar housing, as figure 81 illustrates. Even parts of the site that do not face south, if less forested than other parts, may be good for solar housing. By looking at the steepness of the grade and the extent of forest cover, the developer can pinpoint areas to be avoided and areas that show promise.

Second, some tree species present more problems than others. Evergreen trees, for example, are a problem all year round. Deciduous trees are usually better for solar housing, although some deciduous species are worse than others in terms of shading. Species with dense branching structures, that grow to great heights, and that keep their leaves into the winter present greater problems and bigger shadows for a longer period than certain other species. (This is discussed further in the next section on planting new vegetation.) If the developer or site planner can determine which tree species cause the least shading problems and can couple this with a judgment about the aesthetic value or rarity of tree species, he will be able to identify the most suitable building areas.

Third, if a site is unevenly forested, the wooded areas can be used for open space or buffering. In many projects, open space is either required by ordinance or donated by the developer. In a project with solar homes, forested areas of the site are a natural choice for open space.

Finally, when shading from existing trees is a problem, a developer can consider using a central collector system, a large array of collectors that serves a number of buildings. These collectors must be fairly close to the buildings that they serve because of the problem of heat loss in transferring the heat from collector to building. But using an existing clear area or clearing one for central collectors is an option that may be useful in some situations.

If a developer decides that some trees have to be cleared, he should use shadow patterns to determine which trees actually shade the collector during the important times of the day. He should remember, too, that the placement of the building can be changed at this point if relocation would mean taking down fewer or less valuable trees. Only the trees in the 45- or 50-degree wedge to the south of the collectors will interfere with solar access (figure 82). Also, trees farther away may require only regular top trimming.

New Vegetation: Project Landscaping

There are two major considerations in planning a project's landscaping to protect solar access: the selection of tree species for planting and their location. The following sections discuss both points, presenting some basic principles for landscaping to protect solar access.

Species Selection

Several tree characteristics have an important effect on the extent to which they cast shadows. These include the height at maturity, the spread of the canopy, the growth rate, the duration of the leaf season (for deciduous trees), and the density of the twigs and branches (which affects shading in the winter).

Mature Height and Crown Breadth

Obviously, trees are desirable in landscaping for the protection of solar access—at least when they are not located where they might cast shadows on solar collectors. In selecting species, the developer or site planner must choose those that have a short mature height. Short species with broad crowns provide needed shade in summer and produce shorter shadows in winter. (See figure 83.) Most tree species have a relatively predictable mature height and canopy spread, but others—such as large conifers, eucalyptus, and poplars—continue to grow even after they seem mature.

Literature giving height and widths for various tree species is available, but variations in cli-

Figure 82. Selective Tree Removal from Skyspace

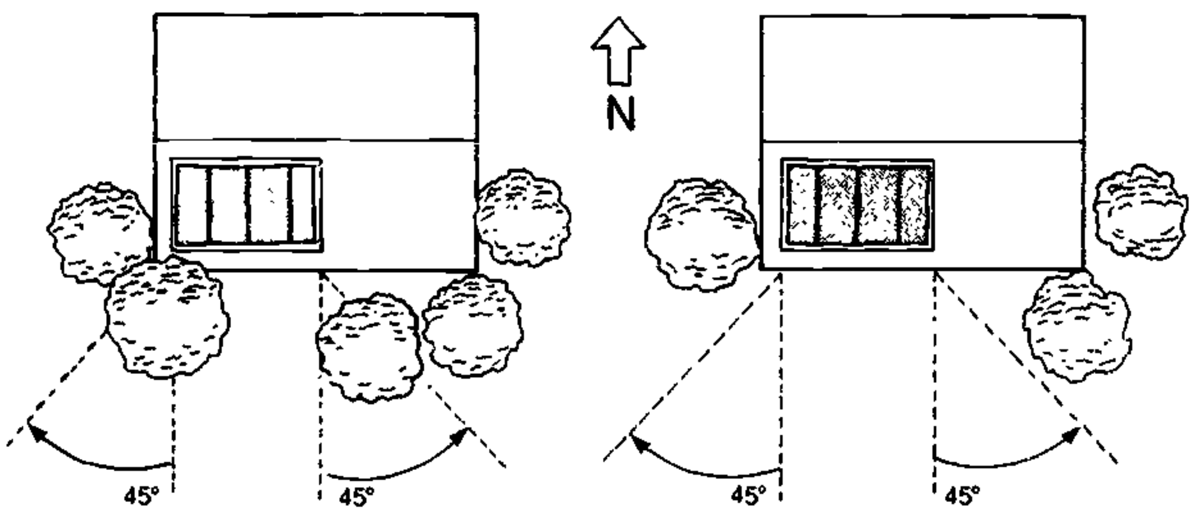
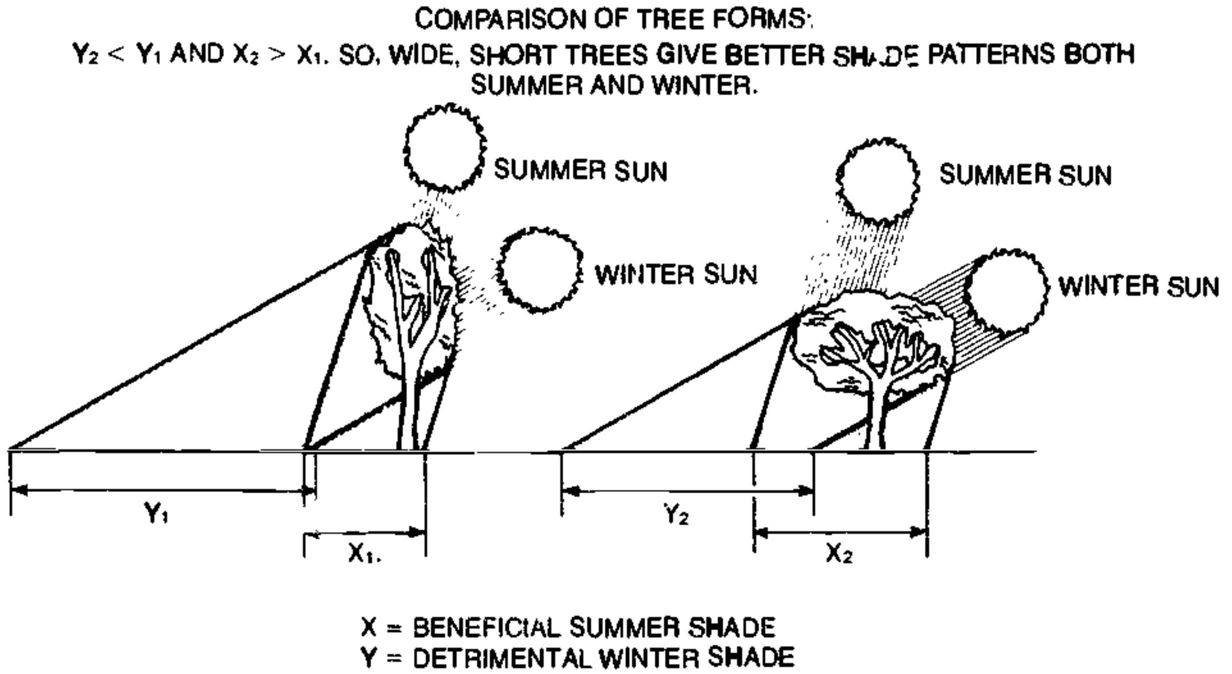


Figure 83. Crown Height and Breadth for Solar Access



mate, soil characteristics, the availability of water, and other factors make it worthwhile to consult a local nurseryman to find out exactly how various species will behave.

Timing of Leaf Season

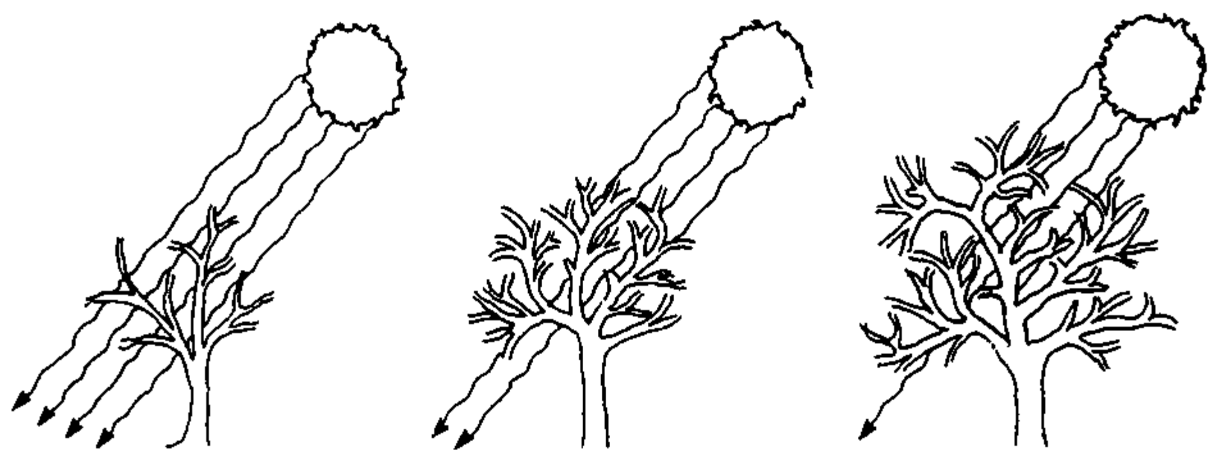
Although deciduous trees obligingly provide shade in the summer and let in the sun in the winter, their timing is sometimes less than perfect. Ideally, leaf-out—the growth of new leaves—in spring would correspond with the end of the heating season and leaf-drop would correspond with the start of the heating season. For the site planner this means finding tree species that have a growing season that coincides as closely as possible with the time when the solar energy system will not be in use. In the spring, this is usually no problem; but in warm winter climates cold periods can occur long after some species have a full leaf cover. In such cases, trees that leaf-out early (such as weeping willows and certain poplars) should not be used where they might shade a space heating collector or south glazing. Similar problems also can occur with species that have a heavy bloom of flowers early in the spring (almond trees, for example) and others that retain fruit or dead leaves late into the fall or all winter long. (Some oaks, for example, keep most of their leaves through the winter.)

In fall, there can be a considerable overlap—in some circumstances, as much as two months—between the arrival of cold weather and complete leaf-fall. During this period, solar energy is readily available, and tree species with early leaf-fall should be selected for planting. Besides the general leaf-fall characteristics of different species, there are several factors that can affect leaf-fall within a species. They are:

Watering and feeding practices. Extended irrigation and late summer fertilizing can boost late growth and slow leaf-fall. Conversely, stopping irrigation in mid-summer can force early leaf fall.

Pruning. Since unpruned trees generally lose their leaves before pruned ones do, minimize pruning and never prune in late summer.

Figure 84. Variations in Bare Twig Density Give Variations in Penetration of Winter Sunlight



Wind. Sheltering trees from wind encourages leaf retention. Sheltered trees may delay their leaf-fall two or three weeks compared to similar trees in windy locations.

These practices can be used to control leaf-fall in order to synchronize it more closely with the beginning of the heating season.

Density of Winter Twigs

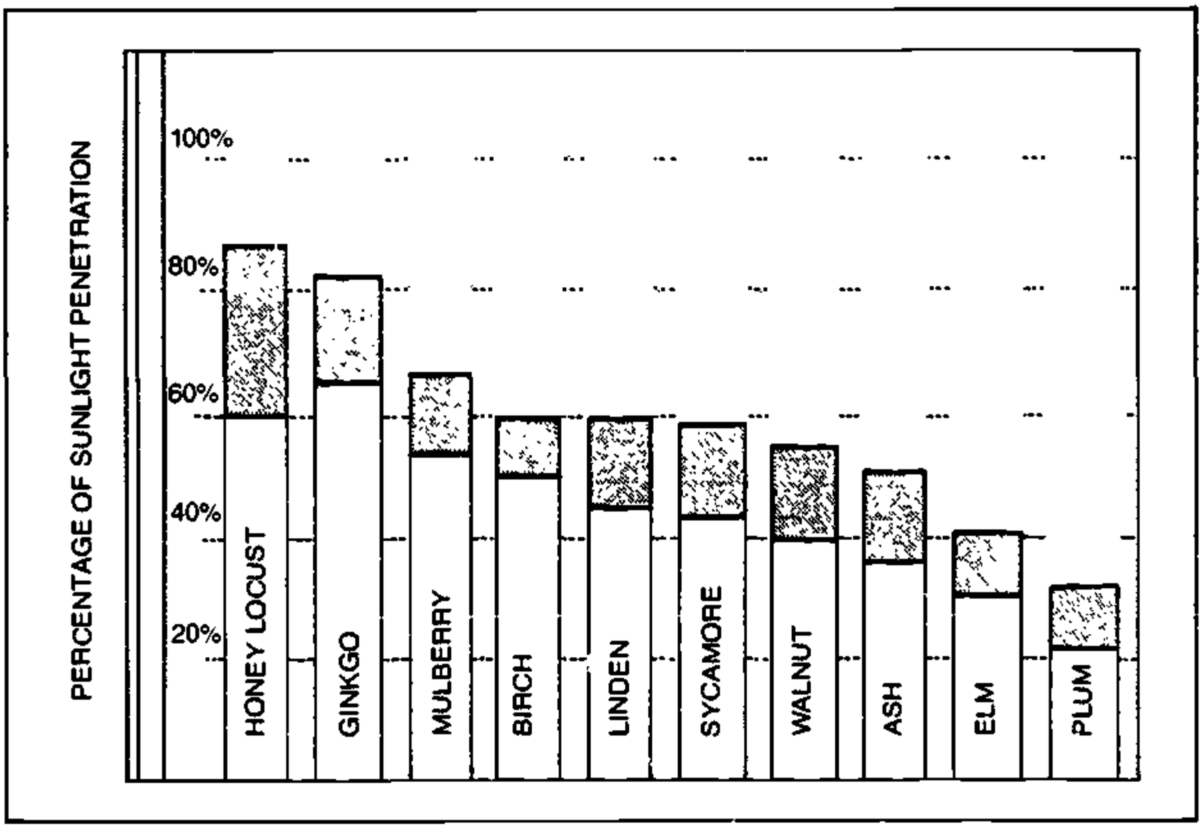
When existing deciduous trees or new plantings stand to the south of a collector, their bare winter branches block sunlight to a certain extent, depending on species, pruning, and maturity (figure 84). Living Systems' preliminary study of unpruned trees of commonly used species in Davis, California, shows that bare winter branches reduce a collector's insolation from 30 to 80 percent.

The bar chart showing bare branch shading (figure 85) shows a range of radiation blockage for a number of different species as well as for individual species. The shaded portion of each bar shows the variation in light meter readings obtained for the various samples; the unshaded portion indicates the minimum shading that can be expected for each tree species. The extent of this variation depends on the number of readings taken for each tree species and the conditions under which the data were collected. This information is likely to vary with the area of the country and the types of trees.

Unfortunately, this kind of information is not likely to be available for common tree species, although radiation blockage information may exist for forest canopies. But forest canopies are not street trees, and it is doubtful whether forestry information is applicable to individual trees or smaller clumps of trees. Therefore, site planners may have to generate this information themselves.

This task is relatively simple. On a clear winter day, the site planner uses a light meter to determine the amount of radiation falling on a spot shaded by a tree's bare branches and compares it to the amount of radiation falling on an unshaded spot near the tree. An incident meter or a common reflective meter fitted with a diffusion lens works best. Alternatively, a common light meter can be focused on a matte, uniform grey card. Changes in radiation are read off the meter dial every few paces as the meter is carried through the shadows cast by the tree's bare branches and twigs. Several trees of each species should be examined; the readings for each species are then averaged It makes no difference whether the light meter reads in f-stops, foot-candles, or some other measurement of radiation; only the difference between the shaded and unshaded measurement matters.

Figure 85. Bare Branch Sun Penetration for Various Tree Species in Davis, California



These are some of the factors that should be considered when selecting species for landscaping a solar project. The site planner or developer is well advised to consult a local nurseryman or other expert familiar with local vegetation.

Location of New Plantings

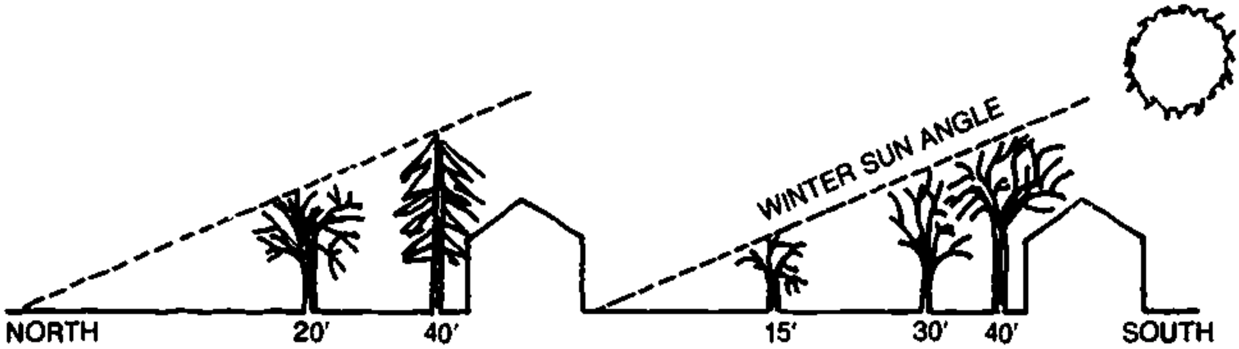
The second major consideration for landscaping is the location of trees to be planted. While the precise location always depends on specific conditions—the topography of the site, the kinds of housing to be used, and so on—it is possible to give some general guidelines for the location of trees to protect solar access.

Simply stated, large trees should not be planted within the 45- or 50-degree wedge of solar skyspace to the south of a solar collector, as figure 86 shows. Large trees should be planted either to the north of buildings or solar collectors or to the south of areas not used for collectors (that is, to the south of roads, parking areas, or industrial areas). Climatically undesirable or exceedingly steep land unsuitable for buildings is especially good for large tree groupings. Smaller groupings should be located where they will not interfere with solar access. Usually, this can be accomplished by siting the taller trees first and smaller trees next.

As planning proceeds, the shadow patterns of proposed trees should be diagrammed in plan view. Unless they are low enough not to block the winter sun, trees should not stand south of collectors in an arc between southeast and southwest. In most climatic zones, buildings should be sited directly to the east or west of trees. Especially at higher latitudes, if the tree has a high crown and a clear trunk, siting close to the south house is best.

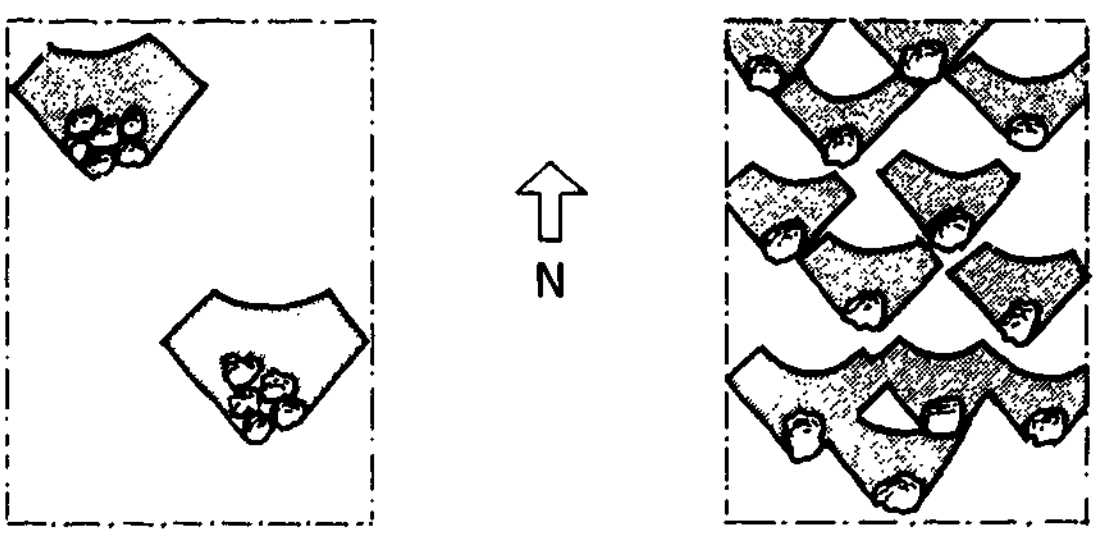
Trees should be planted in groups to assure maximum solar access. Trees in groups cast overlapping shadows, creating less total shaded area than does the same number of separated trees. It is also easier to plan for one larger shadow than for many smaller ones. (See figure 87.)

Figure 86. Tree Siting for Solar Access



A typical planting scheme to allow solar access to south walls. Site tall trees carefully.

Figure 87. Stands of Trees



A dozen trees in two clumps leave large expanses with good access. Dispersed, they shade out most of the site

Taller trees should be planted on the south side of streets rather than on the north. The width of the street and the setbacks act as a buffer to prevent the taller trees' shadows from reaching the solar collector. Although this is a relatively unconventional approach, it both protects solar access and shades the pavement in the summer.

The closer trees are to the south wall of the house, the shorter they must be. This means planting low, shrub-like trees or hedges near the house and taller trees farther away. The developer can imagine a light plane running from the sun to the south wall of the buildings under which trees must fit (figure 88).

Evergreen trees should be limited to the north side of buildings, both because they shade all year round and because they protect houses from strong winter winds. In those parts of the United States where the prevailing winter winds are not generally from the north, evergreens should be located so that they block the winds without blocking solar access.

Maintaining Vegetation: Pruning and Thinning
Whether used to heat or cool, to shade houses or streets, trees usually need pruning or thinning, a skill requiring knowledge and experience. It is best to landscape with trees that require little pruning until they attain their maximum size. Figure 89 shows how thinning works. If thinning becomes necessary, trees should be pruned from the bottom, not from the top. The crown should be thinned rather than topped, because top pruning encourages dense twig growth, which can block needed sun, as figure 90 illustrates. Conversely, cutting the lower branches can increase solar penetration in winter, especially for trees planted near single-story buildings at high latitudes.

Figure 88. Plantings on South Lots

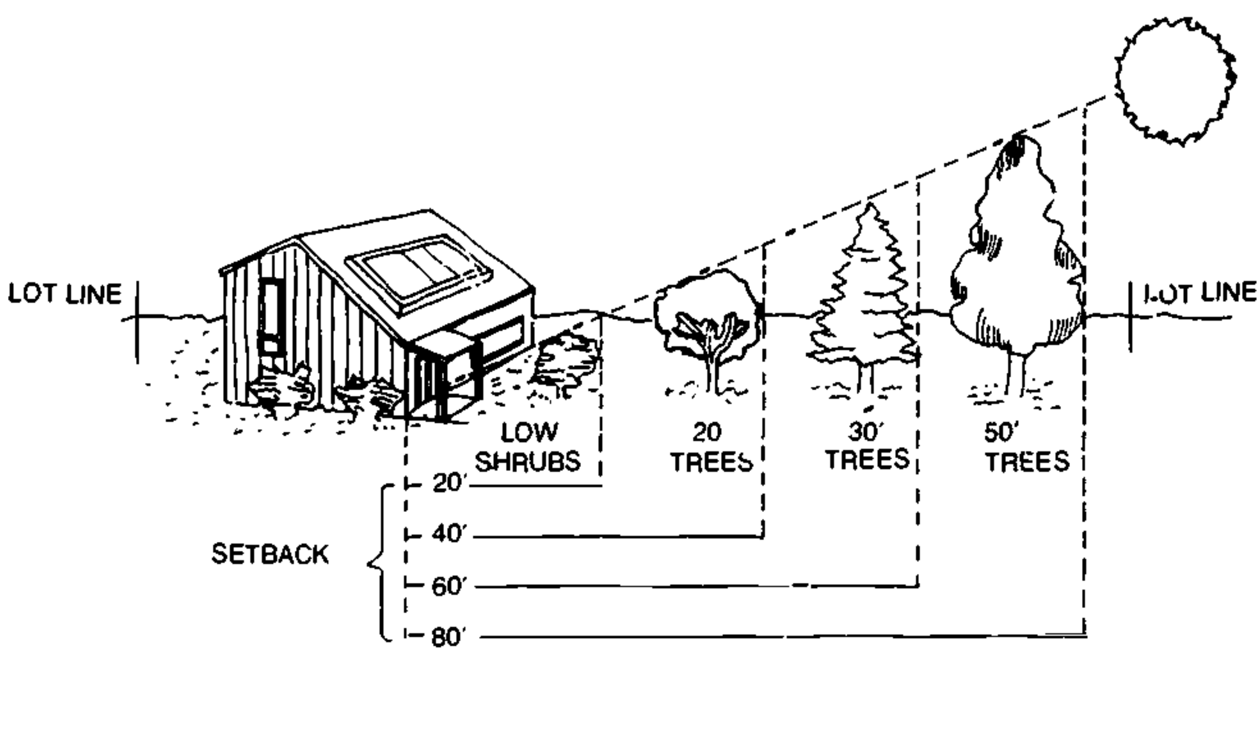


Figure 89. Thinning Trees

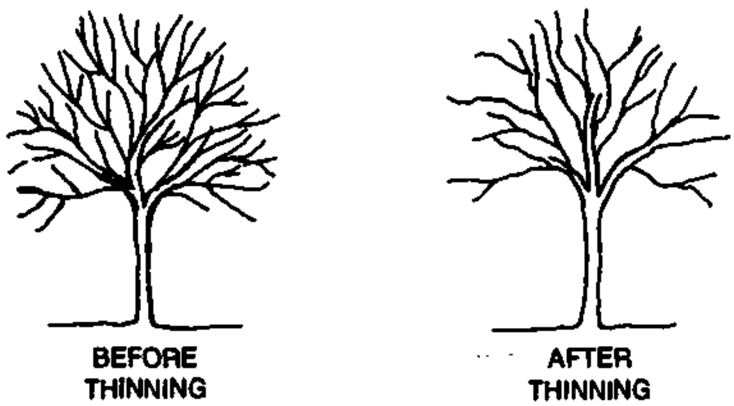
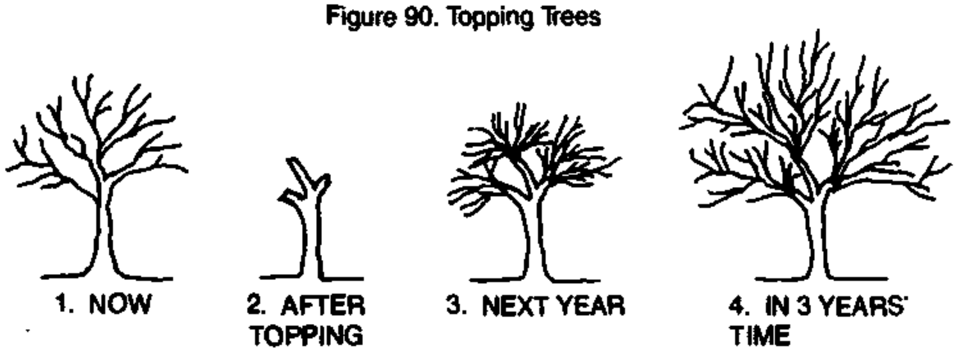


Figure 90. Topping Trees



Guidelines for Plantings

In selecting and locating plantings, the developer should:

Consider mature height when selecting species.

Consider the breadth of the canopy.

Consider whether deciduous or evergreen species are appropriate.

Consider the timing of the leaf season. Does it coincide closely with the beginning and end of the heating season?

Consider the density of twigs and branches for both sun and wind penetration.

Plant trees outside the 45- or 50-degree arc to the south of solar collectors.

Keep the south wall of houses free of shadows between the critical hours on December 21.

Use plan and section drawings to evaluate shadows, conflicts with solar collectors, and beneficial summer shading.

Remember that domestic water heating collectors, swimming pools, and gardens need sunlight during the summer when dwellings, streets, and other paved areas need shade.

Place evergreens to the north of collectors (or north of the entire project) if north winter winds are a problem.

Plant trees in groups rather than individually to attain maximum solar access.

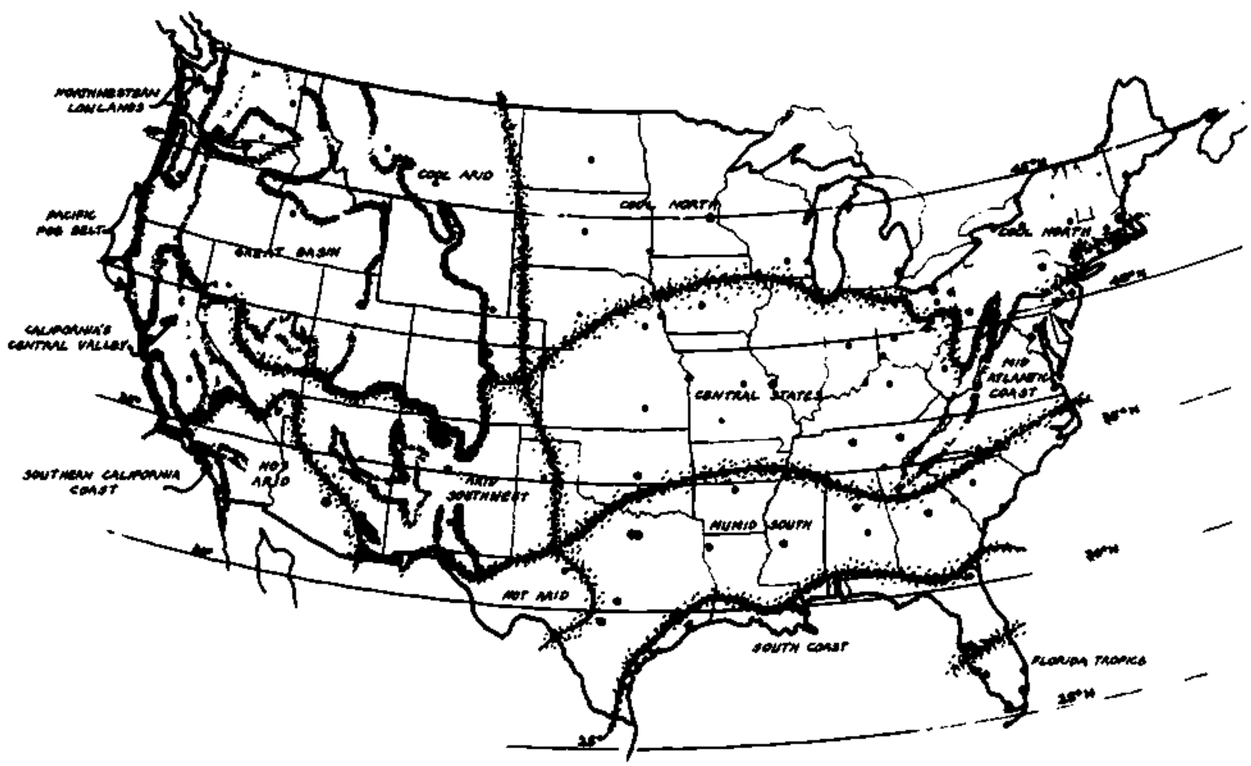
Plant taller street trees on the south side of the street, shorter ones on the north.

Place tall trees away from the solar collector and short trees or bushes near the collector.

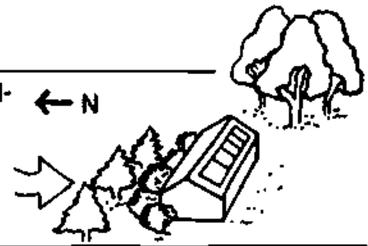
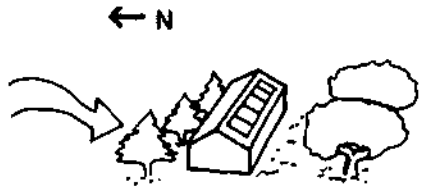
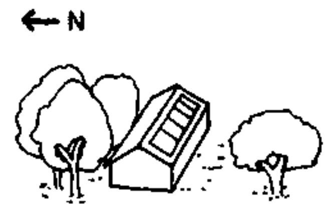
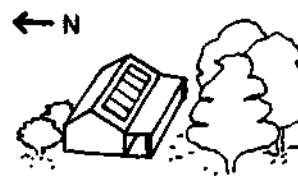
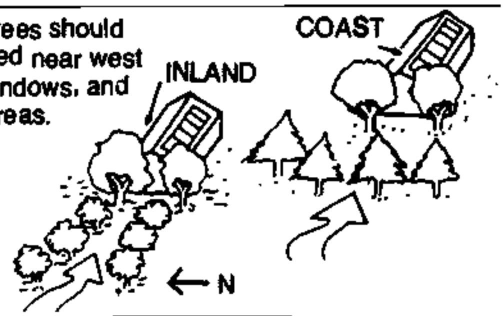
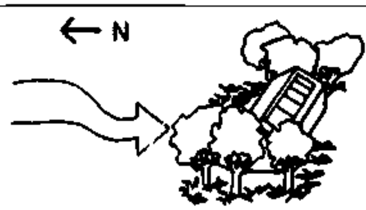
Regional Vegetation Guidelines

Although the vagaries of local climate and the specific nature of the vegetation itself makes it difficult to give exact instructions about landscaping, it is possible to go into somewhat greater detail for various climate zones of the country. The following are guidelines for tree selection and location for the various regions of the country shown in figure 91.

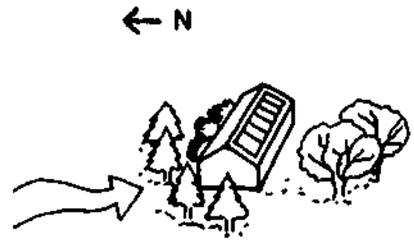
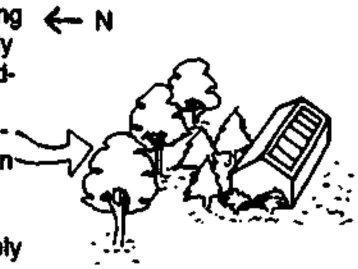
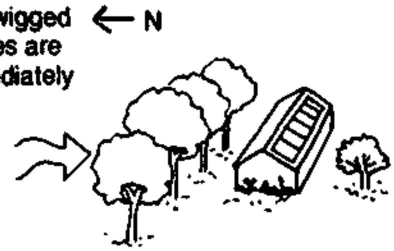
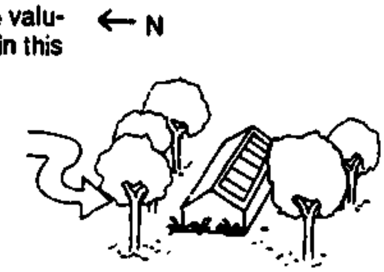
Figure 91. Regional Climate Zone Map



Regional Vegetation Guidelines

REGION	Solar Access Guideline	Wind Buffer Guideline	Shade Guideline	Figure
Pacific Fog Belt	Place taller trees in community open space, rather than putting them close to buildings.	Low evergreen windbreaks, hedges, and shrubs are important for protection from the wind.	This is the only building climate with no need for shading in summer.	
North-western Lowlands	Low solar angles require the use of short trees with broad crowns. For the long heating season deciduous species that get their leaves late in the spring but leaf out quickly are the best choice.	Evergreen windbreaks can be used whenever they do not interfere with solar access.		
Great Basin/Cold Arid	The best location for trees in this region is directly north of buildings. When trees are located to the south, use short, broad, deciduous trees that permit maximum winter sunlight penetration.		Summer shading can also be accomplished by moveable architectural devices that will not shade collectors in winter.	
Arid Southwest	Deciduous species planted south of buildings will provide much-needed shade during the hot season.		Shade paved areas and outdoor use areas as much as possible during the hot season.	
Southern California Coast	Keep south wall and other collectors clear to the south.	On the shoreline, evergreen windbreaks are desirable if they do not block access. On inland sites, vegetation can be planted to funnel ocean breezes for cooling.	Shade trees should be planted near west walls, windows, and paved areas.	
Hot Arid	Provides shade and preserve access by massing trees to the east and west of buildings.	Ground cover plantings help cool the environment while maintaining access, but will still keep breezes flowing beneath tree canopies.		

Regional Vegetation Guidelines

REGION	Solar Access Guideline	Wind Buffer Guideline	Shade Guideline	Figure
Cool North	Trees planted to the south of the building should be short, broad, deciduous species with open twig patterns.	Plant other trees for shelter from wind, to the north and west of buildings. Evergreens are best for windbreaks in winter. When solar access may be blocked, use low shrubs and hedges to divert wind.		
Central U.S.A./ Mid-Atlantic Coast	Keep the south yards free of trees.	Use evergreens to buffer buildings from the wind, but do not block solar access.	Concentrate planting in belts immediately to the north of building rows, shading streets when possible. Plan vegetation carefully, using shadow patterns, when trees are likely to conflict with solar access.	
Humid South	Use broad-leafed, deciduous species, keeping clear of south-wall or roof access. Trees should be massed in lines or groups immediately to the north of building rows.	Use trees with clean trunks and light branching to allow breeze penetration.	Some lightly twigged deciduous trees are possible immediately to the south of buildings.	
South Coast	Preserve all existing trees even at the expense of losing solar access. If possible allow solar access to rooftop water heat collectors. Deciduous species immediately to south of buildings can allow partial sun to south glazing and rooftop collectors in winter.	Use tree species with bare branches for breeze penetration.	Shade is more valuable than sun in this climate.	

Regional Vegetation Guidelines

REGION	Solar Access Guideline	Wind Buffer Guideline	Shade Guideline	Figure
Florida Tropics	Preserve all existing trees even at the expense of losing solar access. If the site is already well forested, presenting the opportunity to shade most houses completely, use a central collector bank for domestic water heating.	Use bare trunk species for breeze penetration.	Shade all paving, windows, and walls and, where possible, all roof areas.	← N 

Two Examples of Solar Site Planning

Determining Planning Criteria
Site Selection
Site Analysis and Preliminary Site Plan
  Climate
  Vegetation and Site Characteristics
Conventional Development
  Preliminary Site Plan
  Detailed Site Plan
    Streets, Lots, and Building Siting
    Landscaping
Planned Unit Development
  Preliminary Site Plan
  Detailed Site Plan
    Streets, Lots, and Building Siting
    Landscaping

The preceding chapters have presented the fundamentals of planning and development to protect solar access and promote proper solar orientation. Drawing on this basic information, this chapter demonstrates how a development plan with solar access protection as a primary objective might be developed for a conventional subdivision and for a planned unit development. A PUD offers a number of advantages in designing a project for good solar access, but a more conventional development also can be laid out to reach this end. Both examples use the same 20-acre site in the southern end of California's Central Valley, near Fresno, at 37 degrees north latitude. The conventional plan shows all single-family residences, each having adequate solar access. The PUD plan will have a somewhat higher density and a mix of housing types.

The decision-making process for planning the development follows this format:

Determination of planning criteria;

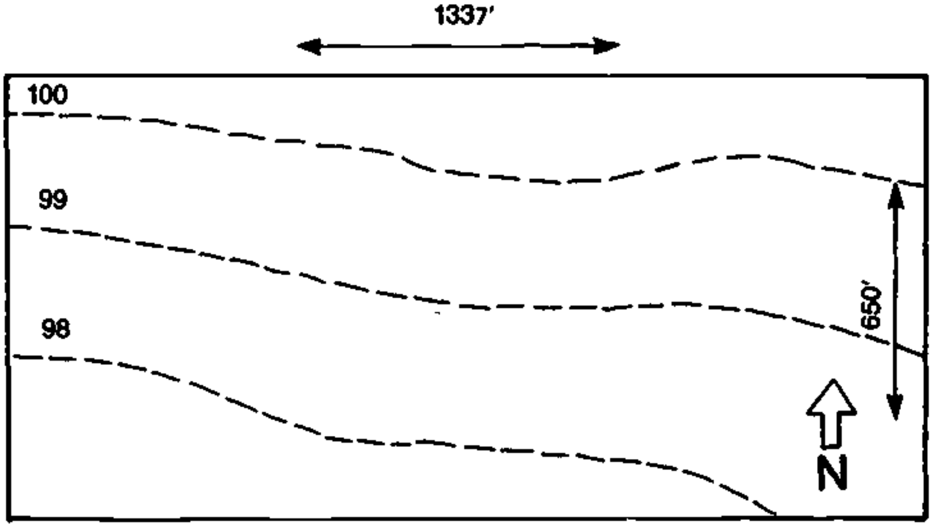
Site analysis and preparation of a preliminary site plan; and

Development of a more detailed site plan, showing individual lots and dwelling locations.

Determining Planning Criteria

The site is located in a county with fairly conventional land-use controls. The parcel is zoned AR-1, agricultural/residential with single-family detached housing and accessory structures allowed by right. The zoning establishes large lot-size requirements—1 dwelling unit per 7,000 square feet of lot area, resulting in an overall density of 5.8 dwelling units per acre, or a total development potential of about 120 dwelling units on the site. Subdivision regulations have typical road and infrastructure standards governing utilities, sewage, water supply, and roads. In ad-

Figure 92. Site Topography



TOTAL AREA
20
ACRES

dition, there are requirements for open-space dedication and for the preservation of existing trees and other major vegetation.

The community also has a PUD provision in its zoning, which can be invoked by application to the city council for a rezoning. The PUD provision is also typical, allowing both a variety of housing types (single-family detached, attached low-rise, and mid- and high-rise buildings) on the same parcel, provided that the project complies with specified standards. As an incentive, the PUD provision allows a maximum density of 7 dwelling units per acre, creating a development potential of up to 140 dwelling units for the 20-acre parcel. As with the conventional zoning provisions, there are requirements for environmental standards, tree preservation, and open space.

Based on these regulatory standards, the developer has selected the following development objectives for the site:

South-wall access for all dwellings;

Maximum energy efficiency, with solar collectors providing most of the seasonal heating requirements and natural cooling;

The preservation of views to the Sierra Nevada mountains;

A central recreation facility and common open space, meeting the minimum standards required for project approval;

Maximum allowable density under both ordinance provisions (conventional and PUD) consistent with market demand in the region. For the PUD development, this means a housing mix of single-family detached, low-rise attached, and mid-rise apartments.

Site Selection

The site shown in figure 92 was chosen because it is essentially flat, with a long east/west axis that maximizes its southern exposure and presents no solar access obstructions. Close to downtown, schools, and a commercial center, it is served by utilities and has a superb view of the mountains.

Site Analysis and Preliminary Site Plan

Climate
California's Central Valley has mild but cloudy and foggy winters. In the hot season, June through September, the temperature averages 100°F. It is dry, and relief from heat can be provided by shading, ventilation, and roof pond coolers. The winter winds and the north winds in the spring, when air temperatures are moderate, can be a significant climatic factor. Summer breezes are light and variable. The growing season lasts all year.

Vegetation and Site Characteristics
The site surface is composed of grass and dark earth; the only trees are along the north border, where shadow conflicts are minimal. There are neither trees nor tall structures on the adjacent lots. This site enjoys beautiful views of the Sierra Nevada to the north and east. The major roadway, on the east edge of the property, connects the site with the local school and a downtown area less than a mile away. The combination of flat terrain, good weather, and short distances make bike riding an attractive mode of transportation. Figure 93 shows the details of the site analysis.

Figure 93. Site Analysis

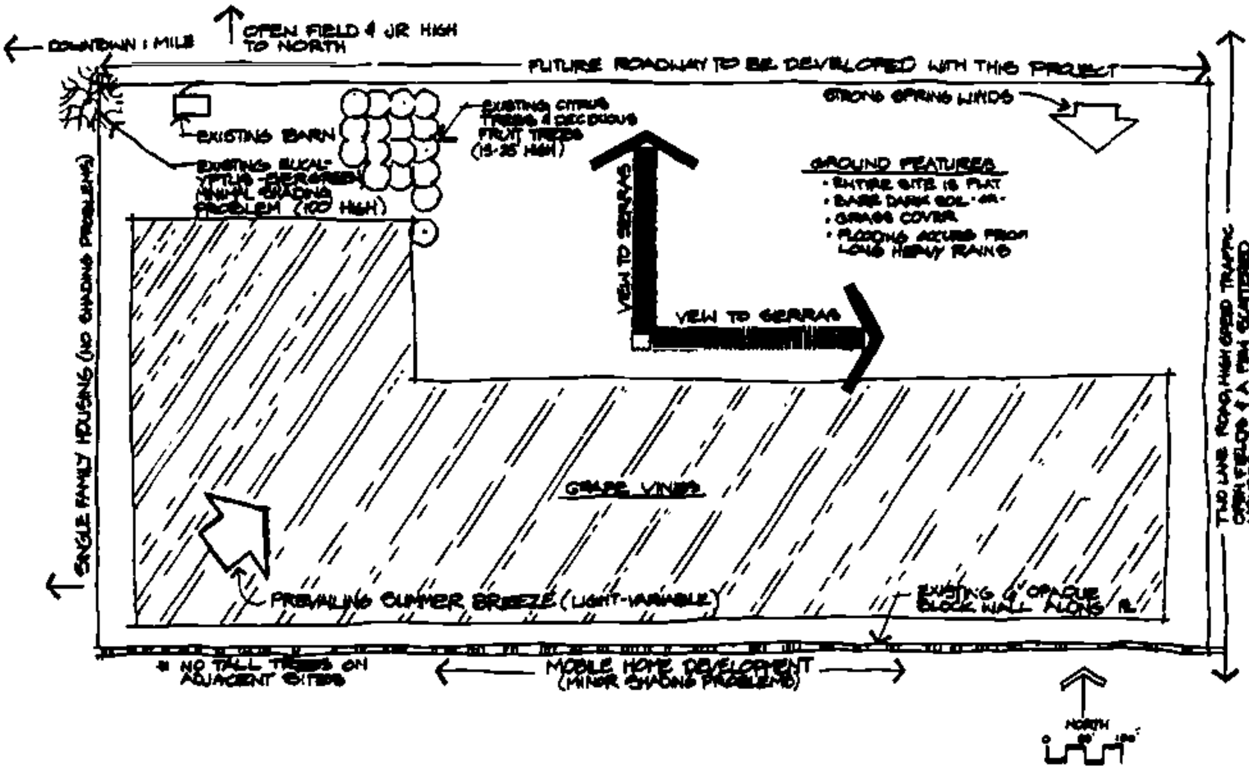


Figure 94. Preliminary Site Plan: Conventional Development

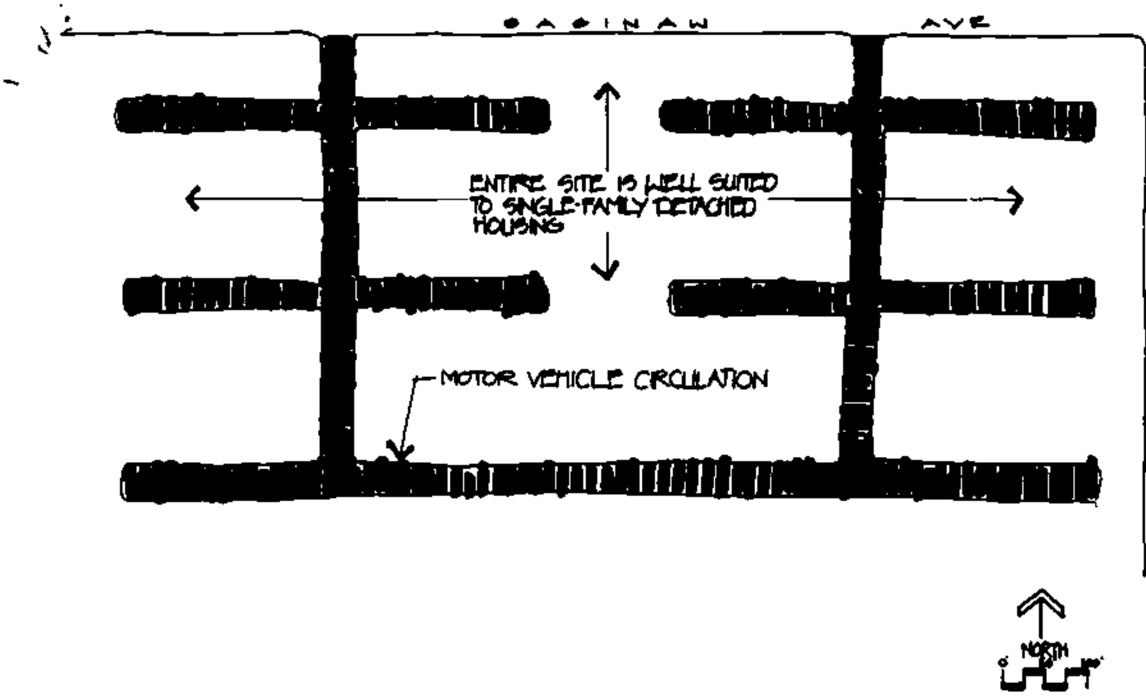
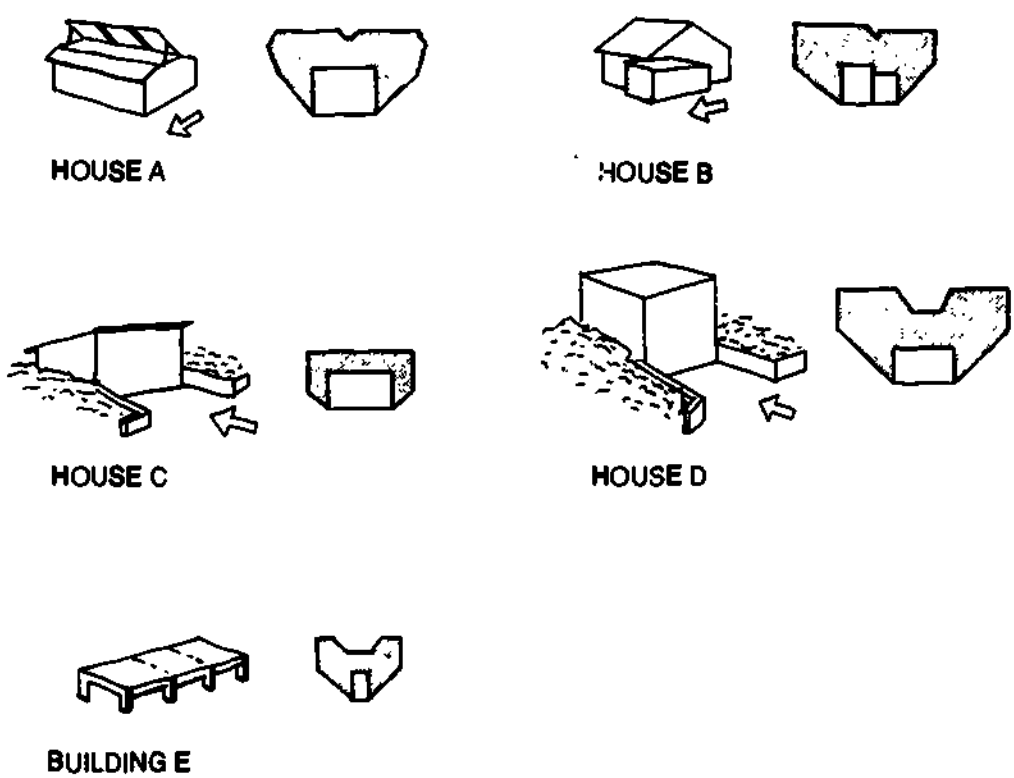


Figure 95. Housing Types



Conventional Development

Preliminary Site Plan
The overall concept (shown in figure 94) stresses the key points:

The entire site is suitable for housing; there are no solar access conflicts.

All local streets run east/west to allow houses to be oriented south. Straight street layout is used for simplification, but curvilinear streets would also be appropriate.

The roadways form view corridors to the north and east.

Detailed Site Plan
Streets, lots, and building siting. The major considerations are:

The street and lot layout allow south orientation of houses.

The houses are located to the north end of each lot to minimize solar access conflicts with other buildings.

The layout of individual buildings and trees is based on shadow patterns.

The general types of single-family housing shown in figure 95 are planned for this project, all using (or having the potential to use) passive south-facing collector area for space heating, rooftop active systems for water heating, and roof ponds for natural cooling.

House A—One-story house on east/west axis with roof pond
House B—One-story house with partially flat roof area
House C—One-story shed-roofed house
House D—Two-story flat-roofed house
Building E—Carports

Figure 96 shows one possible layout of housing on the site. Shadow patterns indicate that all dwellings have south-wall solar access. Allowing solar access to the south wall ensures adequate sun for rooftop water heating systems. South yards are made as large as possible on most lots.

Figure 96. Building Shadow Plan: Conventional Development

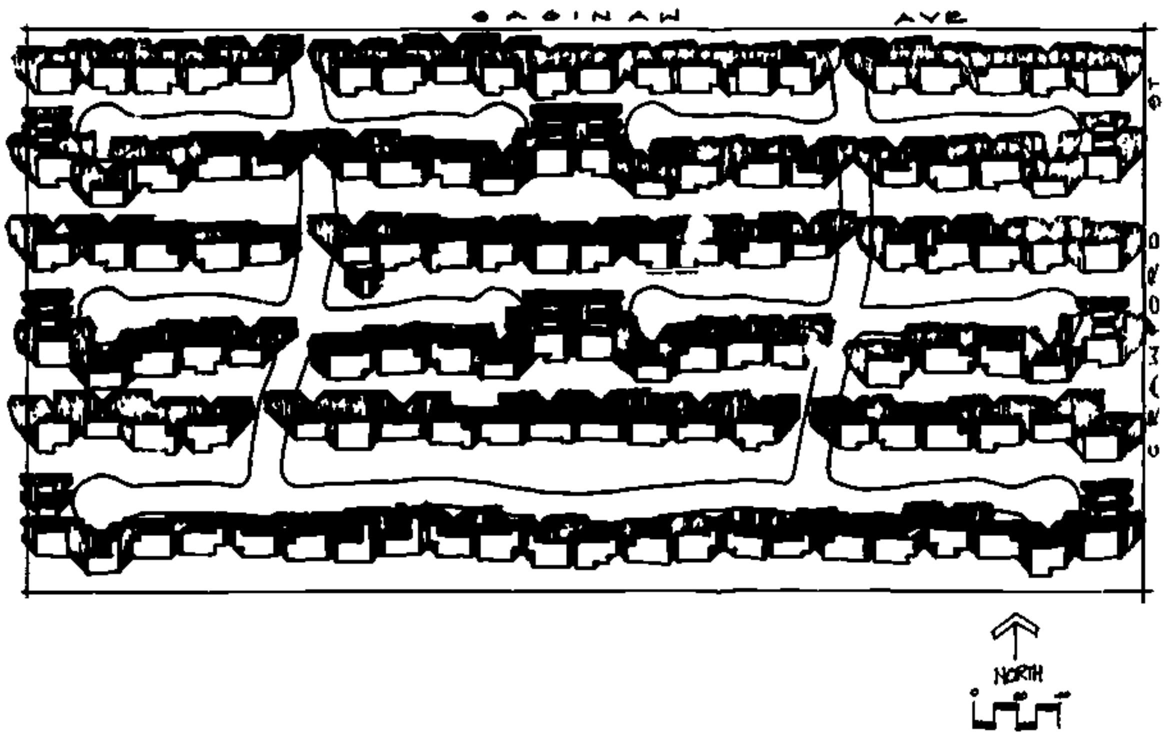


Figure 97. Tree Types

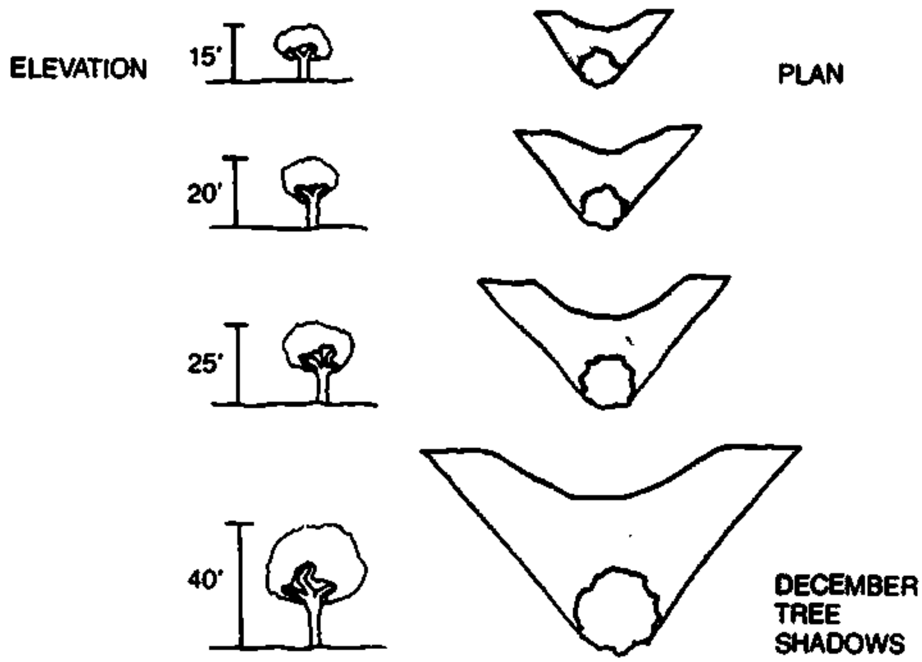


Figure 98. Tree Shadow Plan: Conventional Development

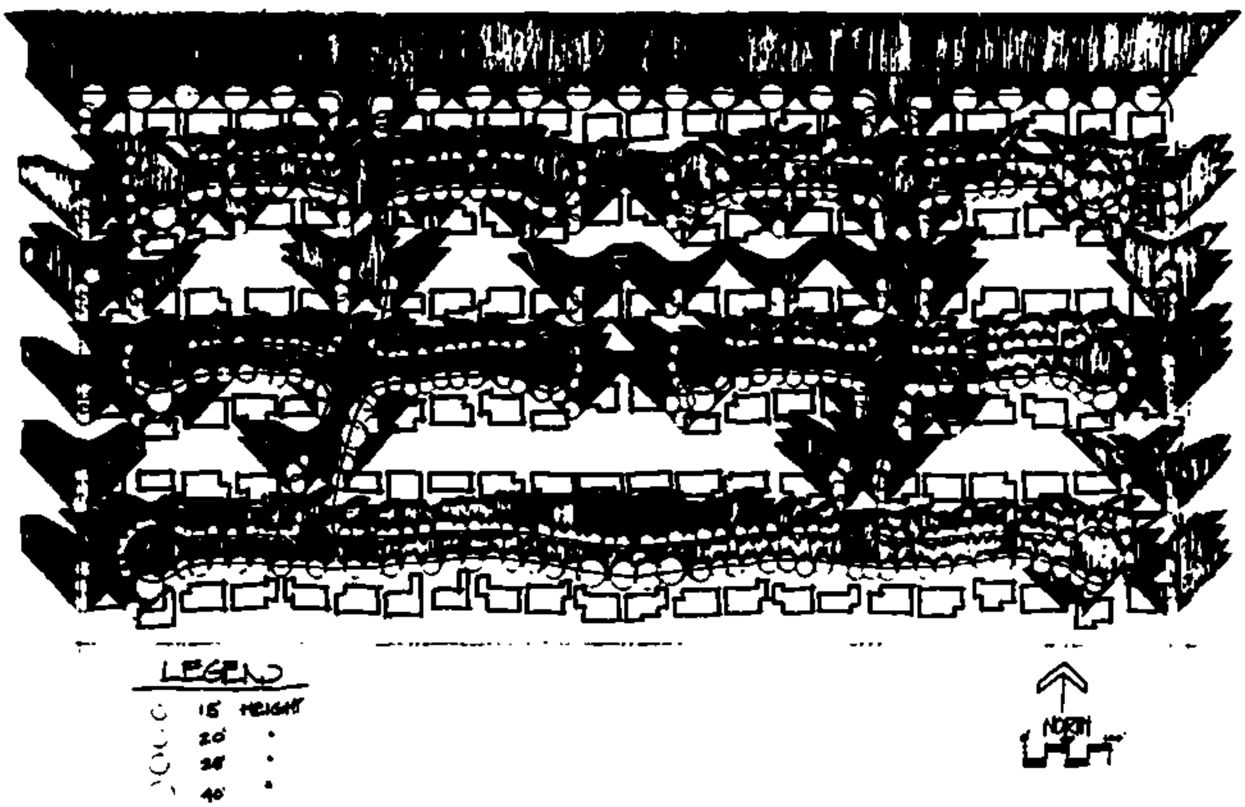
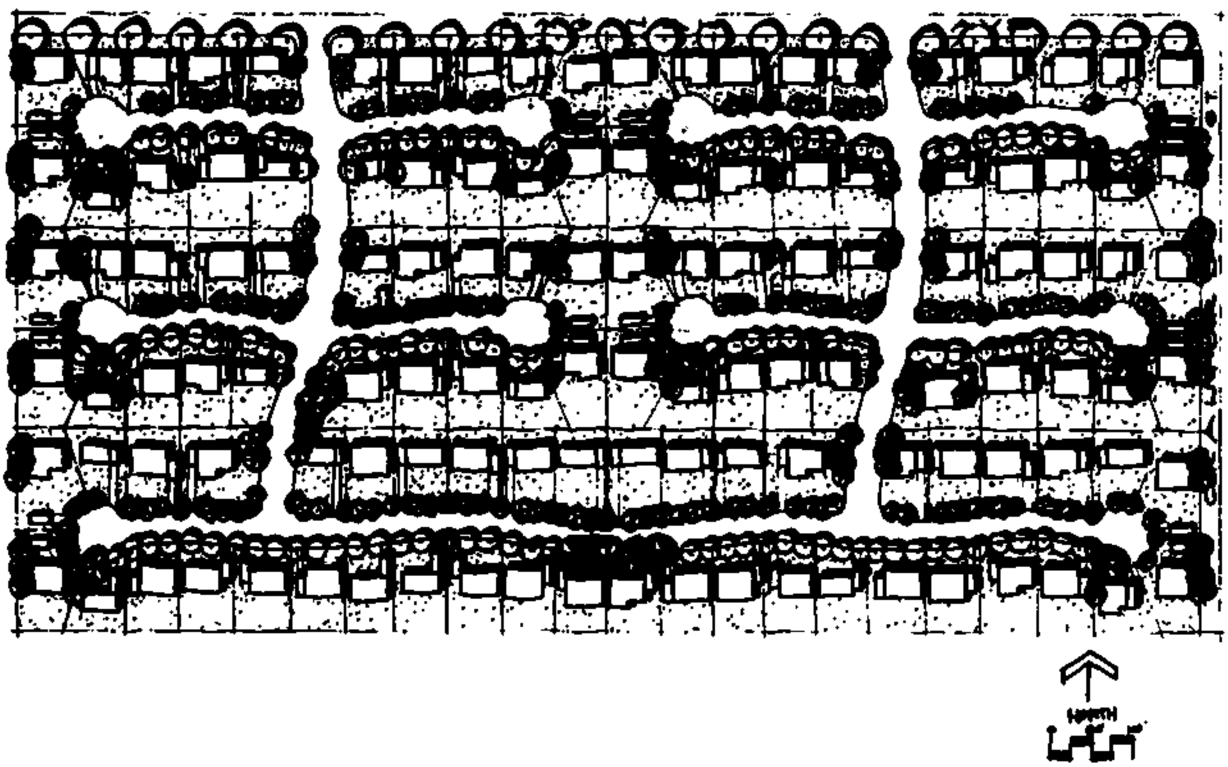


Figure 99. Site Master Plan: Conventional Development



Landscaping. For planning purposes, a few types of trees and shrubs were chosen; ranging in height from 15 feet to 40 feet, each group has both deciduous and evergreen species. Figure 97 shows the December tree shadows for these types.

For planning purposes, a deciduous tree should be evaluated as if it were evergreen, because its bare branches block a significant amount of sunlight. This is a very conservative approach, since many passive systems still work even when shaded by bare branches. At higher latitudes, this approach may be too restrictive.

Figure 98 shows a layout for trees superimposed on the housing layout. A significant number of trees have been used without shading any south walls of the dwellings.

The site plan is completed by combining the building and tree shadow plans in a manner consistent with the development objectives. The resulting plan is shown in figure 99.

Planned Unit Development

Preliminary Site Plan

The major site uses, presented in figure 100, can be summarized as follows:

Housing is grouped in clusters, each cluster having a focal open space.

A centralized community open space and recreation center is linked to the clusters.

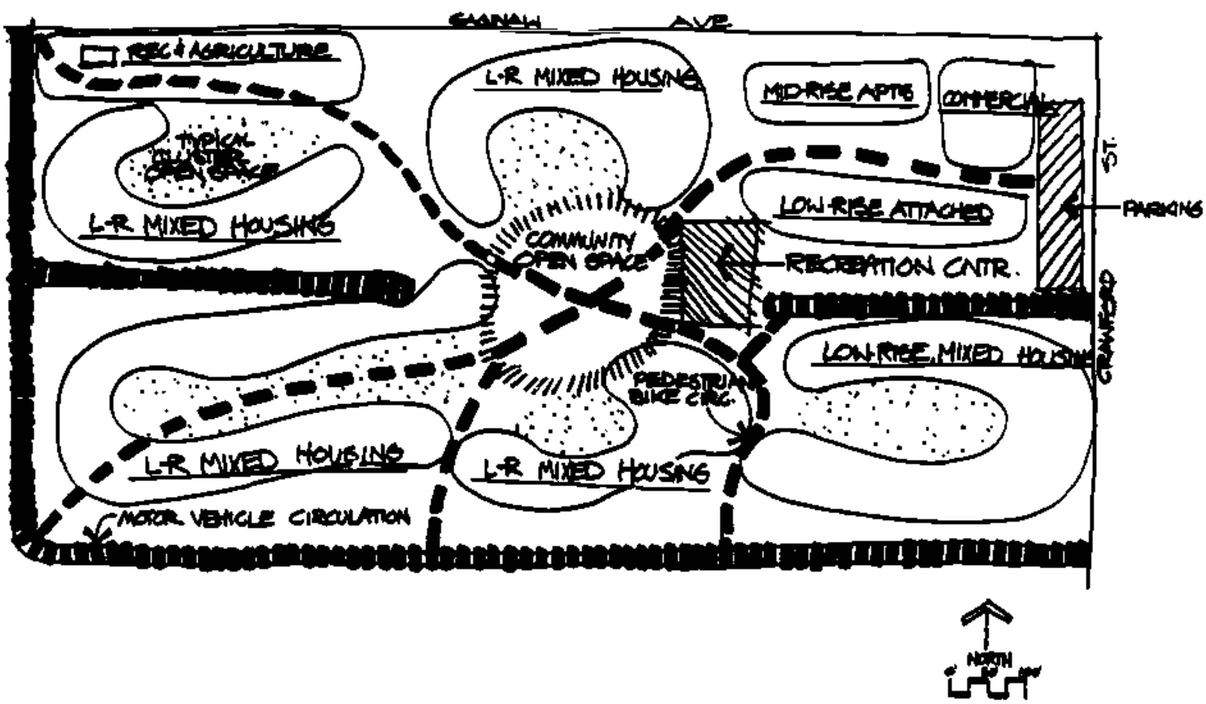
The tallest building, a mid-rise apartment, is located at the north edge of the site.

Auto circulation is kept to the periphery of the site, and a bike/pedestrian path is used for internal traffic.

The commercial center lies at the intersection of the two existing roads.

The highest density housing is located closest to the existing roads.

Figure 100. Major Land Uses: PUD



The existing barn and fruit trees are used as an agricultural center.

The open spaces double as storm drainage and percolation areas.

Detailed Site Plan
Streets, lots, and building siting

All access streets run east/west to allow north/south lots.

Only lots with roof clerestory collectors, buildings (see above, figure 35) do not run north/south. Clerestories gain solar access through their roofs.

When possible, car circulation is kept to the periphery in order to concentrate and integrate community and cluster open spaces.

Layout of individual buildings and trees is based on shadow patterns.

All the general housing types used in the conventional neighborhood are used in the PUD, with the additions shown in figure 101 as follows:

Apartment F—Two-story, four-unit apartment building. South wall requires solar access.

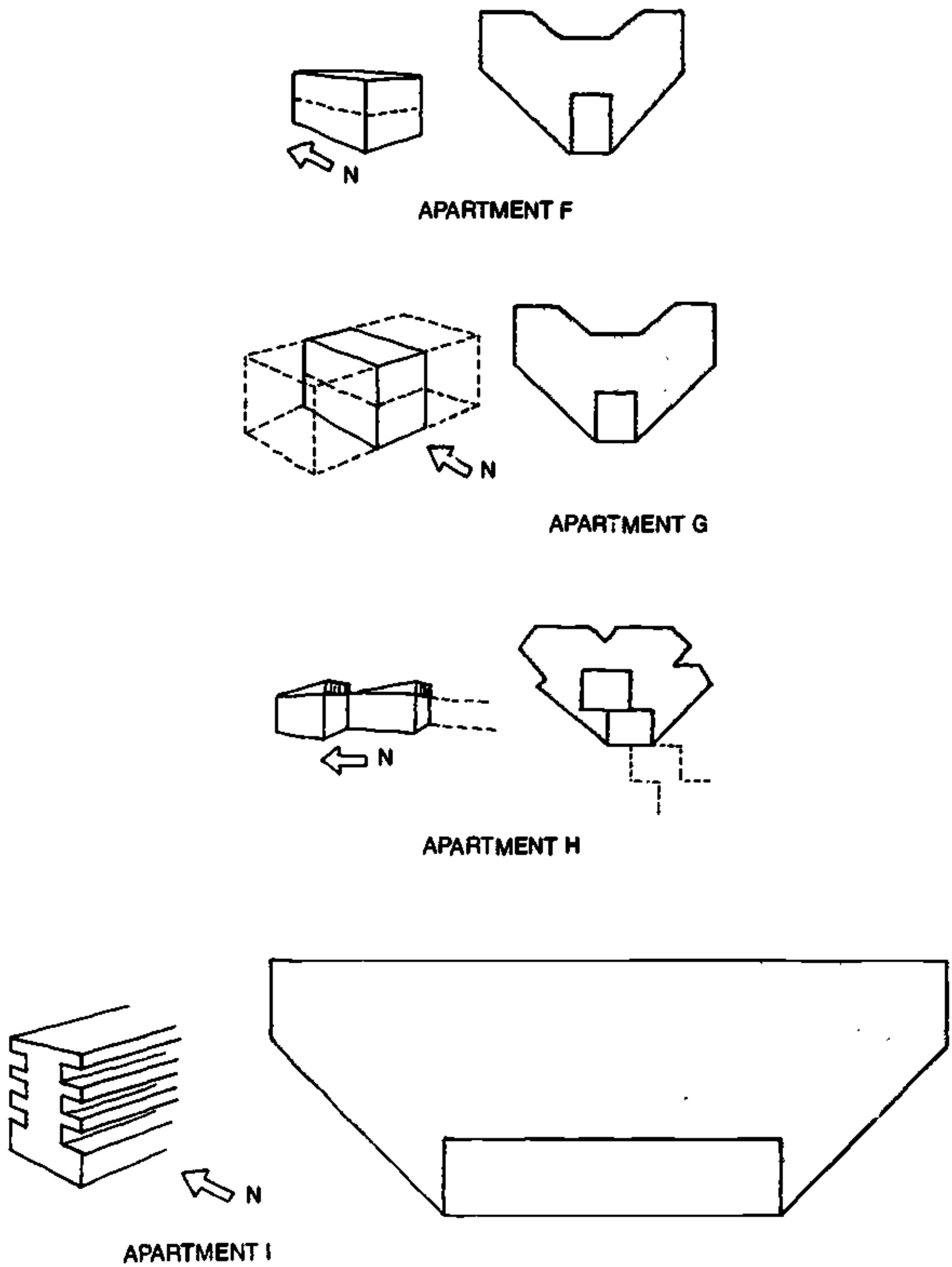
Apartment G—Low-rise attached townhouses. Most are two-story although some one-story units are included. All require solar access to the base of the south wall.

Apartment H—Attached low-rise apartments. Solar access is through the roof for passive space heating. South walls receive sun for half the day in winter. Private yard space is on the east or west.

Apartment I—Four-story, mid-rise apartment building. This is a single-loaded exterior corridor plan to allow south access and cross-ventilation to all units. Patios are provided on the south side.

Figure 102 shows an alternative housing layout that achieves south-wall and, in many cases, south-yard solar access for all dwellings. Carports generally are located on the opposite side of the street along the southern edge of the neighborhood to maximize solar access to south yards. The following section drawings are used to determine best placements of carports:

Figure 101. Apartment Types: PUD



Alternative 1 in figure 102 shows carports adjacent to the houses. Solar access to the south yard is blocked by the carport in winter, but the street is half-shaded in summer.

Alternative 2 shows the carport on the south (opposite) side of the street. The shadow of the deciduous street trees allows increased winter sun to the larger south yard, but the street has minimal summer shade.

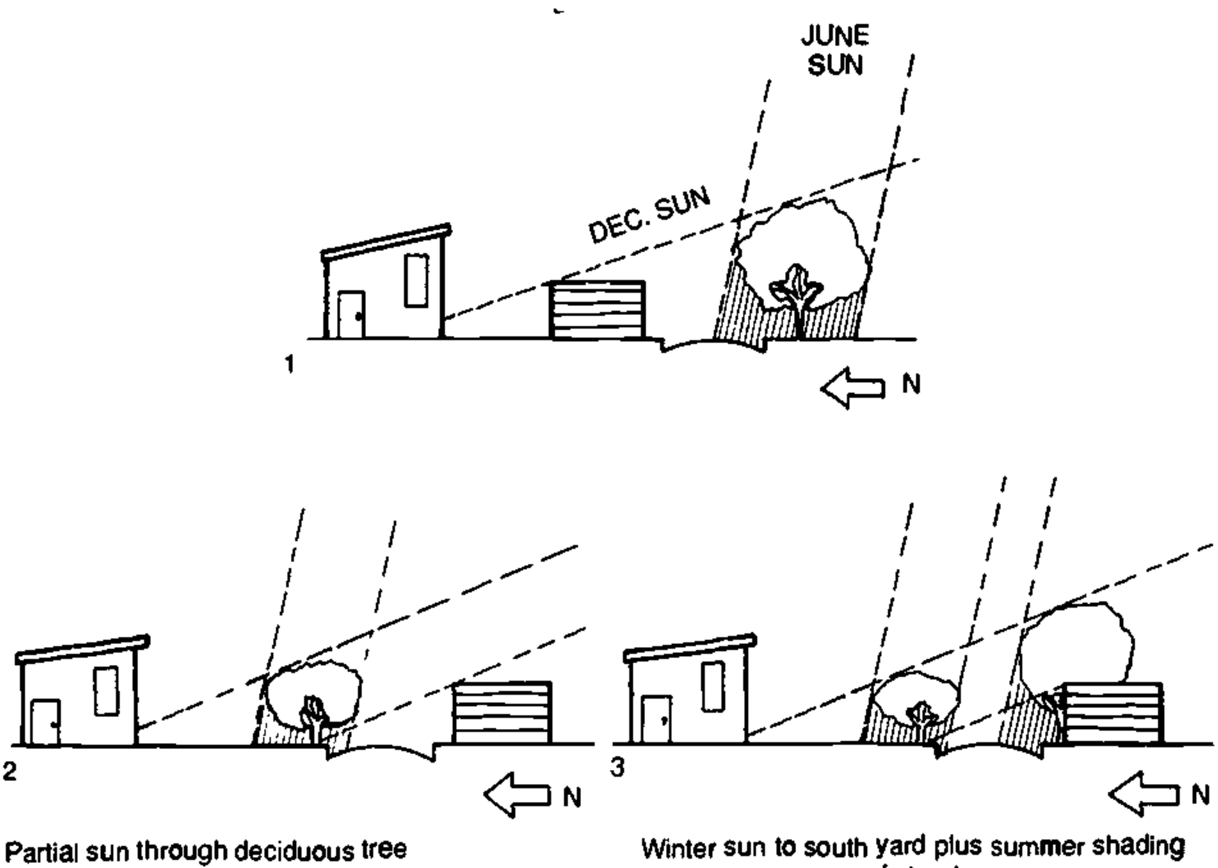
Alternative 3 shows that alternating street trees and carports results in optimum sun and shade patterns.

Shadow patterns are developed for each of the housing types; the buildings and shadow patterns are arranged on the site plan in various ways that are consistent with the land-use diagram developed earlier. Building placement is optimal when all south walls obtain the best solar access and are not shaded by adjacent structures. Figure 103 shows this arrangement.

Landscaping. As for trees, a process similar to that used in the conventional development is used for the PUD—the tree types are identified and shadow patterns developed. The trees and shadow patterns are then organized on the site plan to accomplish the major development objective—summer shading of yard areas and west walls of structures and winter sun access to south walls and rooftops. Figure 104 shows the resulting tree plan.

Finally, as in the conventional development, all the elements are combined into a final site master plan. Buildings and trees are located to achieve the best circulation, land use, and solar access development objectives. Figure 105 shows the completed PUD development, fully planned for both optimal solar access and conventional development goals.

Figure 102. Housing Layout Alternatives



Partial sun through deciduous tree

Winter sun to south yard plus summer shading of street

Figure 103. Building Shadow Plan: PUD

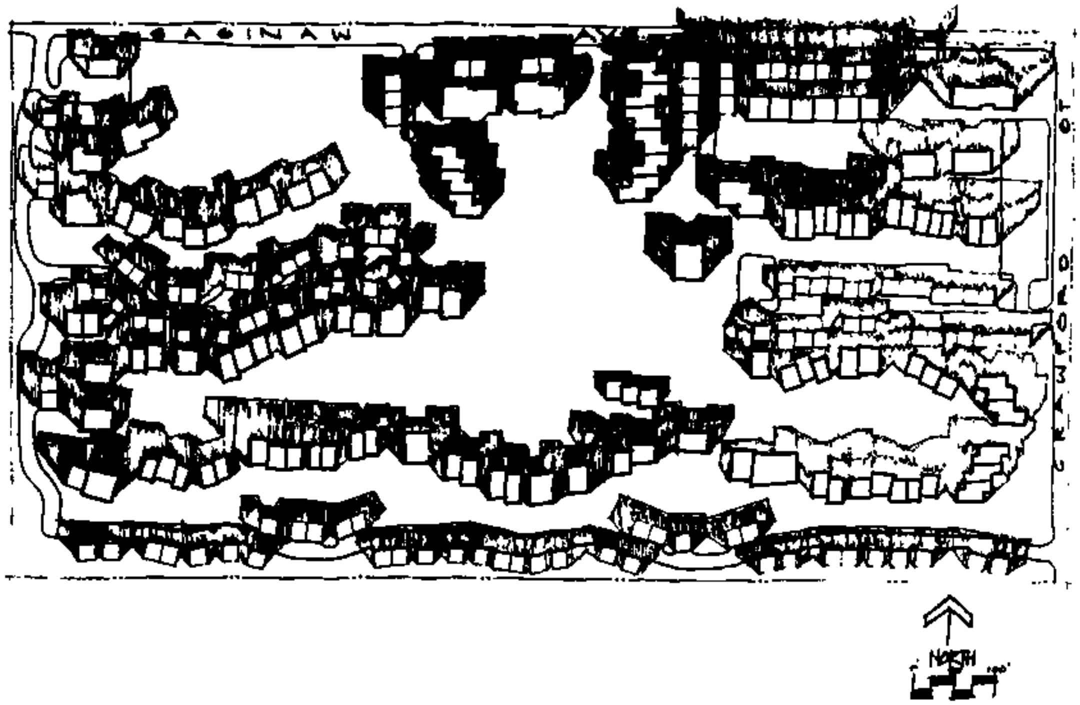


Figure 104. Shadow Plan: PUD

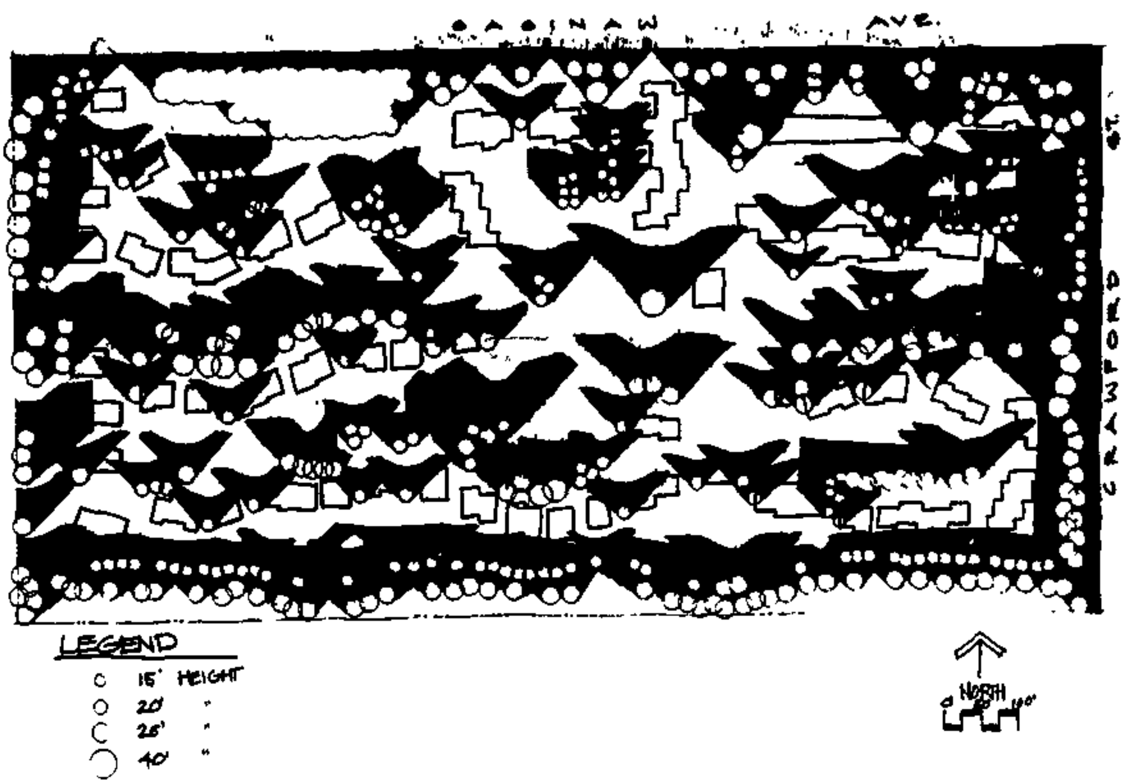
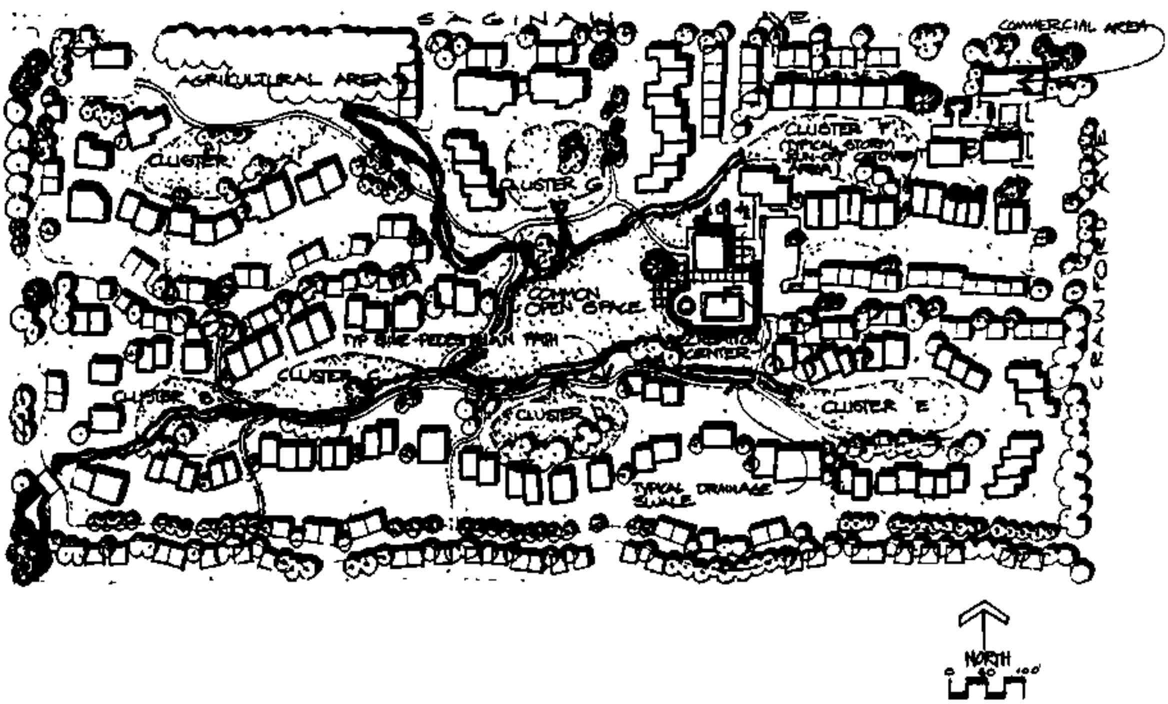


Figure 105. Site Master Plan: PUD



Private Agreements to Protect Solar Access: Covenants and Easements

The techniques discussed up to this point suggest strategies for protecting solar access during build out. But in order to be effective, solar access must also be protected after lots or buildings are sold and occupied. A carelessly planted tree, for example, can undo careful site planning and development design, and an addition to a house or a new garage can cast shadows across areas planned for the use of solar collectors.

It is for these reasons that developers must consider the use of private agreements to protect future access as well as to ensure existing solar access in new developments.

Private agreements are common techniques used to preserve desirable characteristics of new developments, such as common open space, large front yards, and architectural design. Private agreements suitable for solar access protection include restrictive covenants and easements. Both types of agreements are familiar to developers and public officials and are widely used in the development process. They are especially attractive to developers and homeowners because they offer a greater degree of private control over restrictions affecting development. This flexibility is desirable because solar access protection often involves restricting activities on one lot to protect adjacent parcels. If agreements can be negotiated between lot owners, solar access can be assured with minimal public involvement.

Restrictive Covenants

The most common private agreement is the restrictive covenant. A restrictive covenant is a contract between two or more persons which involves mutual promises of reciprocal benefits and burdens among consenting landowners. This means that all persons involved in a covenant benefit from it and that all are burdened by restricting an activity such as the construction of an otherwise allowable structure that could cast a shadow on the solar collector of a neighbor. The covenant is considered restrictive because it requires the parties to restrict development opportunities. A restrictive covenant is a covenant not to do something, as compared with an affirmative covenant which is an agreement for the parties to take a specific action.

Restrictive covenants are often created by a developer at the time a subdivision or development is approved by a local government. The restrictions apply to lots within the development and are usually inserted into the deeds of all parcels to be developed. The covenants may be enforced by the developer, by a lot owner within the development, or, frequently, by a homeowner's association created to manage certain aspects of the development. Because these covenants often appear in the deeds, they are also called "deed restrictions."

Some technical issues involving restrictive covenants arise because they are legal instruments. These issues include privity of estate and whether the covenant "touches and concerns" the land. Although these issues have a bearing on the enforceability of the restriction, they do not concern the developer and will not be discussed in this chapter. The existence of such problems suggests, however, that the developer should have the proposed covenant reviewed by a lawyer, especially if the covenant terms are unfamiliar. The developer's major concern should be that the covenant is enforceable and that it is likely to accomplish its stated purpose, such as protecting solar access or permitting the installation and use of solar energy equipment.

Restrictive covenants are similar to zoning in a number of ways. Like public regulations, restrictive covenants can guide private development decisions and can affect future, as well as existing, development within the subdivision or project. And, like zoning, covenants can create barriers to solar energy use and solar access, or they can encourage site design and development to assure solar access protection. In fact, restrictive covenants are sometimes called "private zoning" and are a major type of land use control in some communities (notably Houston, Texas).

Restrictive Covenants as Barriers to Solar Energy Use and Solar Access

Restrictive covenants can affect development actions by lot owners. Covenants can prohibit certain types of land uses, such as non-residential uses in a residential development; restrict development to certain types of structures, such as single-family detached housing; and even bar development altogether in certain areas of the site, such as open spaces or greenbelts.

Barriers to solar access and solar energy use may arise inadvertently through the enforcement and operation of restrictive covenants. The developer or homeowner's association may not have intended to restrict solar energy use or solar access, but the application of the particular restriction may do this nonetheless.

Developers who wish to encourage the installation and use of solar energy collectors and the protection of solar access should consider the effects of restrictive covenants on these objectives. For example, covenants that control architectural features of structures within the development or that require the planting or preservation of vegetation between homes can discourage solar access planning.

Architectural standards are enforced in many subdivisions for the purposes of maintaining property values and perpetuating desirable neighborhood characteristics. These standards can be specified in several ways: (1) in a covenant that requires, for example, all residences to conform to an architectural style (French Provincial, Gothic, Tudor); (2) by an architectural review board created by a covenant and empowered to deny or grant petitions to construct or materially alter dwellings within the subdivision; or (3) by a homeowner's association which all landowners in the subdivision are bound by covenant to join. Regardless of how these standards are instituted, they can inhibit the installation of solar energy collectors if the design of the collectors is perceived to be in violation of the covenant or against the architectural judgment of the board members or association officers.

A developer who desires to encourage the use of solar energy collectors and to promote some degree of architectural harmony might consider modifying architectural standards within the development to accommodate solar collectors. The developer may choose to exempt some collector designs from the architectural standards, or at least give collectors a presumption of architectural compatibility. Columbia, Maryland, for example, is developing architectural guidelines for its architectural review board to use in evaluating the integration of solar collectors into housing design. It is likely that such guidelines will have to be considered by many other developments whose design guidelines now restrict solar collector installation.

Developers sometimes insert covenants in all deeds to require landowners to maintain plantings of vegetation near the property lines between residences. Trees or tall hedgerows, shielding the residences from outside view, afford greater privacy than the landowners otherwise would enjoy and contribute to a more pleasing landscape. But, as was noted earlier, vegetation can affect access to sunlight. Developers who wish to have both beautiful landscaping and solar energy collectors might consider prescribing maximum heights on trees and other vegetation to prevent an obvious conflict between a covenant that requires vegetation to be planted near the property line and one that restricts shadow lengths across the property line.

Restrictive Covenants and Solar Access Protection

A covenant provision to protect solar access is printed below. In using this type of provision, it must be remembered that the laws affecting restrictive covenants vary from state to state. This example is not meant as a model but may provide guidance to developers considering similar provisions in their own developments.

Restrictive Covenants of [Name of Development] in [Municipality or County]

The following restrictive covenants are incorporated in this deed and in all other deeds to parcels within the [*name of development*], which is located in [*complete legal description of the development*], as recorded in [*legal records of named county*]. These covenants are binding upon all present and future owners of land within this development with the same effect as if they were incorporated in each subsequent deed.

(1) No vegetation, structure, fixture, or other object shall be so situated that it casts a shadow at a distance greater than 20 feet (6.1 meters) across any property line on December 21 between the hours of [9 a.m. and 3 p.m. Standard Time], provided that this restriction does not apply to utility wires and similar objects which obstruct little light and which are needed and situated for reasonable use of the property in a manner consistent with other covenants in this deed. By adopting this covenant, the landowners within this development recognize the desirability of creating and maintaining a common plan to ensure access to direct sunlight on all parcels within the development for public health, aesthetic, and other purposes, specifically including access to sunlight for solar energy collectors.

The two introductory sentences would preface the list of restrictive covenants, which in some developments might number 20 or more. Of course, "covenant (1)" alone would be valid were it one in a list of other covenants if the list were validly incorporated into a plat or deed and the covenant were consistent with others in the list.

The phrase "vegetation, structure, fixture, or other objects," with the stated exclusions, includes everything that might cast an appreciable shadow. It should not be necessary in the covenant to define individual words, but the planner should be familiar with some of the key concepts of the covenant.

"Vegetation" is self-explanatory. Discussions on the different shading characteristics of tree species are in the chapter on trees.

"Structure" can be defined as "anything constructed or installed or portable that requires for normal use a location on a parcel of land. This includes any movable structure located on land which can be used either temporarily or permanently for housing, business, commercial, agricultural, or office purposes." This is a modified definition of one in American Law Institute, *A Model Land Development Code* (1976).

"Fixture" may be defined as "personal property which has become so affixed to real property that it cannot be removed without damage to the real property." For convenience, this definition sometimes is included within "structure," by adding a sentence such as, "It also includes fences, billboards, poles, pipelines, transmission lines, and advertising signs."

The restriction on shadows is designed to allow the siting of solar energy collectors in yards as well as on structures. The sample distance of 20 feet in the covenant example should be adjusted, of course, to fit specific circumstances. The distance selected will depend on such factors as latitude, topography, lot size, and density of structures. Developers considering covenant provisions similar to this example also may wish to restrict shading only across the northern lot line, instead of across *any* lot line. Whether a proposed object will violate the covenant can be determined with knowledge of the latitude of the development and the proposed height and distance from the lot line of the object. The shadow length tables in Preliminary Site Planning can be used to calculate the appropriate distances across any lot line, and the shadow projection table in Appendix III can be used to calculate appropriate distances across northern lot lines.

Three hours before and three hours after solar noon normally are adequate for the effective operation of solar energy collectors, both active and passive. These times generally correspond to the

45-degree azimuths used to define solar skyspace in most latitudes, but they also can be adjusted. For example, six hours might be sufficient in winter, while seven or eight might be needed during the summer, when the solar energy system might be used for air conditioning. It is unrealistic to expect the land surface to be free of shadows at all times, because this would require an unobstructed landscape from horizon to horizon.

Standard Time might be selected as the reference time because of its practicality. Mean solar time might be preferable from a technical point of view, because it corresponds more accurately with the position of the sun (the sun is directly south at mean solar noon), but Standard Time is more familiar. This requires that mean solar time must be converted to Standard Time by the drafter of the provision. The developer must keep in mind the necessity of this conversion (which depends on the longitude of the development site) when using Standard Time in the covenant provision.

The covenant creates a common plan to provide direct sunlight for rather broad purposes, not solely for solar energy collectors, because this allows greater flexibility in the interpretation of the covenant with regard to changing technologies and neighborhood conditions.

Accommodating Change

Changing circumstances and changing technologies must be kept in mind when considering covenants of this type. Statutes in some states limit the applicability of covenant provisions. State legislatures, realizing that covenant restrictions might not be appropriate if enforced in perpetuity, limit the duration of such restrictions. For example, Georgia limits restrictive covenants to 20 years, Massachusetts to 30 years, and Minnesota to 40 years. These statutes allow parties to renew the covenants and restrictions anytime before the end of the statutory term.

Easements

Easements are another type of private agreement that can be used to protect solar access. Easements are interests in real property that can be transferred like the property itself. One of the most common examples is a utility easement, a right purchased or otherwise obtained by a utility company to run utility lines across property. Easements for solar access would be negotiated by individual lot owners or by a developer with the owner of adjacent property. Essentially, the owner of the burdened property agrees to keep areas of his property free of objects that could shade the neighboring solar collector. Easements are recorded with a public agency, usually the city clerk or registrar of deeds.

A solar easement is a negative easement. An affirmative easement allows somebody to enter or cross land belonging to someone else. A negative easement prevents one landowner from doing something that otherwise would be allowed, such as erecting a building that can cast a shadow on a solar collector on an adjacent lot.

Easements for solar access protection may be drafted under existing property law in all states. A number of states, however, have adopted specific legislation which sets forth the technical requirements for solar access easements. A landowner considering solar access easements should check the state law to make sure that the easements are both recordable and enforceable.

Shown below is a solar access easement.* Its content and format are only illustrative.

Solar Skyspace Easement

Section 1. Estates Burdened and Benefited by the Solar Skyspace Easement

[Grantor(s)] hereby conveys, grants, and warrants to [Grantee(s)] for the sum of [$________] a negative easement to restrict in accordance with the following terms the future use and development of the real property of Grantor(s) recorded as follows with the [registrar of deeds] of [County]:

The boundaries of the solar skyspace for the solar collector(s) of Grantee(s) are as follows:

> [Alternative (A)] All space over the above-described property of the Grantor(s) at a height greater than [30 feet].
>
> [Alternative (B)] All space at a height greater than [30 feet] over the above-described property of the Grantor(s), extending from a line parallel to and [25 feet] from the [front] property line along [Plum Drive] to a line parallel to and [55 feet] from the [rear] property line at the [east] edge of the [Plum Orchard Subdivision].

*Thomas, Miller, and Robbins. *Overcoming Legal Uncertainties About Use of Solar Energy Systems*, p. 45

[Alternative (C)] All space over the above-described property of the Grantor(s) at a height above the burdened property that is described by a plane that intersects the property line between the burdened and benefited estates and that extends [southward] over the burdened property at an angle.

Section 2. Conditions of the Easement

[Alternative (A)] No structure, vegetation, or activity of land use other than the ones which exist on the effective date of this easement and which are not required to be removed herein or excepted herein shall cast a shadow on the solar energy collector(s) of Grantee(s) described above during the time specified in this section. Exceptions are utility lines, antennas, wires, and poles that in the aggregate do not obstruct more than 1 percent of the light that otherwise would be received at the solar energy collector(s) and [other exceptions].

[Optional] A shadow shall not be cast from [3 hours] before noon to [3 hours] after noon from [September 22 through March 21] and from [4 hours] before noon to [4 hours] after noon from [March 22 through September 21], when all times refer to mean solar time.

[Alternative (B)] No structure, vegetation, or activity or land use other than the ones which exist on the effective date of this easement and which are not required to be removed herein or excepted herein shall penetrate the airspace at a height greater than [______] ~~over the [above-described real property of~~ Grantor(s)/following areas of the above-described real property of the Grantor(s) [______]] with the exception of [______].

Section 3. Effect and Termination

Burdens and benefits of this easement are transferable and run with the land to subsequent grantees of the Grantor(s) and of the Grantee(s). This solar skyspace easement shall remain in effect until use of the solar energy collector(s) described above is abandoned but not sooner than [10 years] after creation of this easement, or until the Grantee(s) and Grantor(s) or their successors in interest terminate it.

Section 4. Definitions

Define *solar energy collector*, *solar skyspace* and *structure*.

Section 5. (Optional)

The attached map showing the affected properties and the protected areas of the solar skyspace is incorporated as part of this instrument.

Section 6. [Other matters depending upon state laws: notary clause, signatures, attestation, and recordation].

Several alternatives are presented for Section 1 and Section 2 of the sample easement. In Section 1, three different alternative clauses are used to define the boundary of the easement established by the instrument. Alternative (A) uses an approach analogous to the height restriction of a conventional prescriptive zoning ordinance. Alternative (B) uses a similar approach but limits the development restriction to only a portion of the burdened lot. Alternative (C) uses an approach similar to the bulk plane provisions in some zoning ordinances.

Section 2 also considers alternative conditions. Two alternative sections of the easement are provided, but they accomplish almost identical objectives. The restriction can be defined as in Alternative (A), where a three-dimensional space is defined within which development is allowed, similar to the bulk plane and building envelope techniques found in public zoning. Alternative (B) is similar to a performance standard limiting the times of day which a collector must remain unshaded. The choices are similar to the land-use control techniques discussed in the companion guidebook.

Protecting Solar Access.

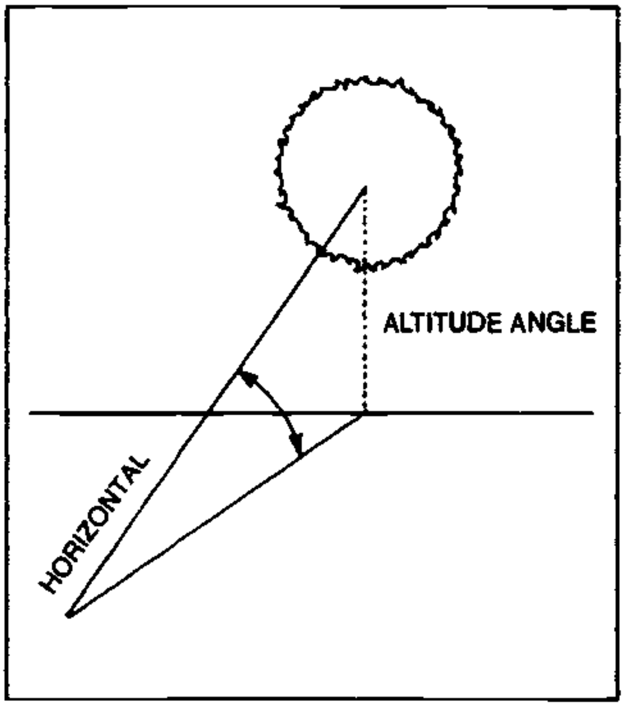
In both easement provisions, the numbers and phrases inserted in the brackets depend on a number of factors—such as the latitude and topography of the site, the use and location of the proposed collector system, the solar access objectives of the parties creating the easement, and the degree of development restriction both parties are willing to tolerate to achieve solar access. Thus, the number and descriptive terms must be created on a case-by-case basis and no uniform suggestions can be made.

It must be remembered that an easement to protect solar access affects only the lots benefited or burdened by it. Usually, easements are individually negotiated and often when someone wishes to install a solar collector.

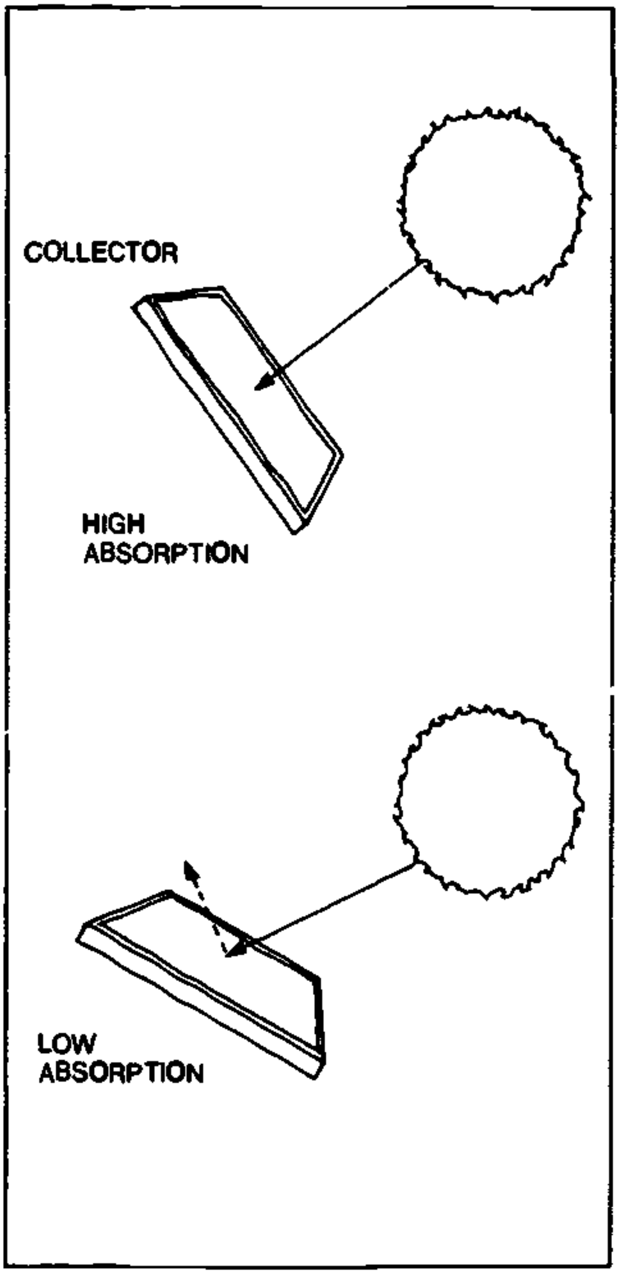
Appendix I: Glossary

ACTIVE (OR INDIRECT) SOLAR ENERGY SYSTEM—a system in which the collector and thermal storage components are separated and require a pump or fan to circulate the solar-heated fluid between them. The choice of location for active collectors is flexible; rooftops are commonly used.

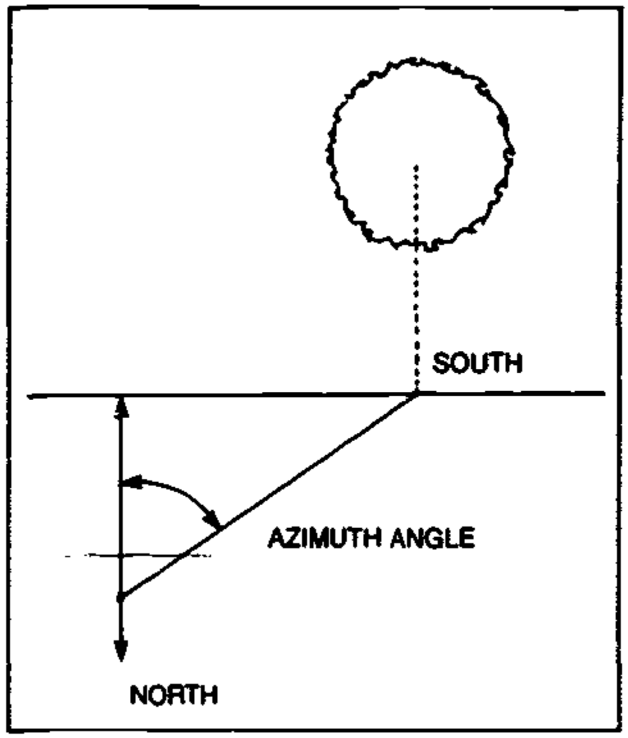
ALTITUDE—one of two angles used to specify the sun's position at any given time; altitude is the angle of the sun above the horizontal.



ANGLE OF INCIDENCE—the angle at which direct sunlight strikes a surface. The angle of incidence affects the amount of energy absorbed by a solar collector. Sunlight with an incident angle close to 90° (perpendicular to the surface) tends to be absorbed, while lower angles tend to reflect light.

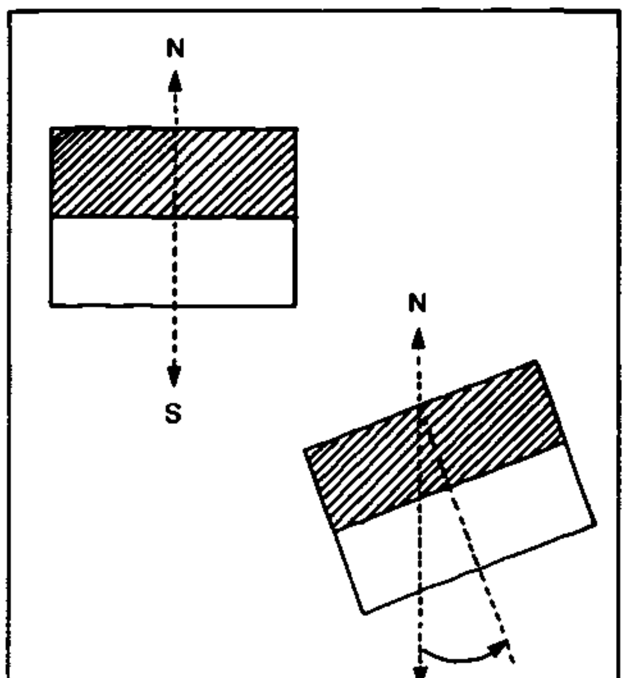


AZIMUTH (SOLAR)—one of two angles used to specify the sun's position at any given time; azimuth is the angle between south and the point on the horizon directly below the sun (Anderson, 1976). South is 0° and angles to the east and west are described as 0° to 180°E or 0° to 180°W.

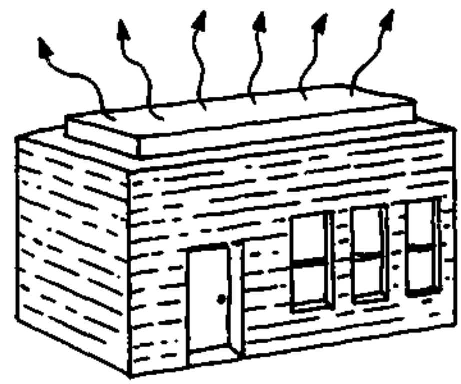


BTU OR BRITISH THERMAL UNIT—the quantity of heat required to raise one pound of water one degree F.

BUILDING ORIENTATION—the relationship of a building to south. A building's orientation is specified by the direction of its longest axis.



COLD NIGHT SKY—the low effective temperature of the sky on a clear night. Most of the heat radiated from a body outdoors is given off to the cold night sky. This process is used by radiative natural cooling systems having roof ponds. Sky access for such systems is not crucial, with over 80% of radiant heat loss occurring to the sky 30° above the horizon.

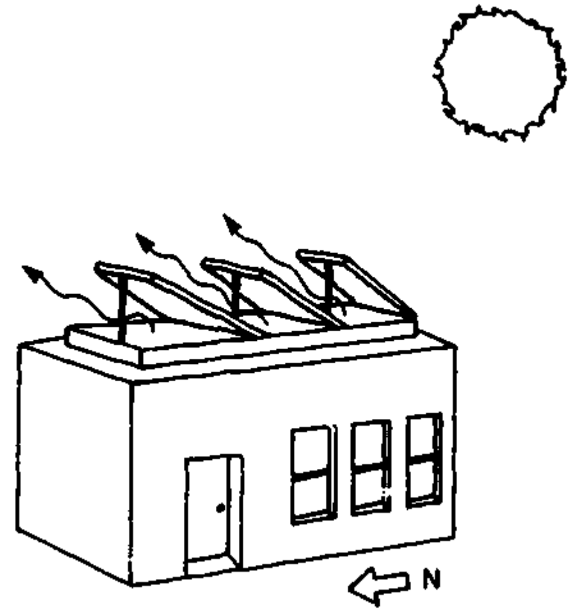


Roof pond dissipating heat to the cold night sky.

COLLECTOR—any device or area that uses the sun's energy to heat domestic water or to heat, cool, or light a living space. This broad definition includes not only familiar space and domestic water heating system collectors but also collectors for space cooling.

COLLECTOR EFFICIENCY— the percentage of sunlight reaching the collector surface that can be extracted as useful energy (Anderson, 1976).

COOL NORTH SKY—the area of north sky with relatively low temperature on clear days. Heat can be dissipated during the day from a surface shaded from the sun and facing north. This is made possible by the cool spot in the sky that occurs at the point opposite from and at a right angle to the sun. Averaged over the day, the coolest spot is due north at an angle of elevation from the horizon equal to 90° minus the altitude of the sun at noon. This can be an effective method for natural cooling using shaded roof pond systems.



Daytime heat dissipation to the cool north sky.

DIFFUSE SUNLIGHT—sunlight that reaches the earth after being reflected off atmospheric particles. On a cloudy day, diffuse light may account for all the sunlight received at the surface. Diffuse sunlight comes along no set path; it generally comes from the entire skyvault, the most coming from the area of the sky near the sun.

DIRECT SOLAR ENERGY SYSTEM—see Passive Solar Energy Systems.

DIRECT SUNLIGHT—sunlight that comes straight from the sun. Skyspace angles and most solar planning guidelines are based on direct sunlight. Direct sunlight has higher intensity than diffused sunlight.

DISSIPATOR—any device used to dissipate or reject heat in natural cooling systems. Dissipators typically work by radiation, evaporation, or conduction. They range from operable windows used for night ventilation to more complex roof ponds.

EASEMENT—a form of private agreement with the potential to protect solar access. Easements are interests in property, which can be bought and sold like property itself. A common example is the utility easement.

ENERGY SHARING—collecting solar energy on one building or portion of a building and distributing it to other areas which have poor solar access.

EVAPORATIVE COOLING—cooling provided by the evaporation of water. Evaporative cooling uses water's ability to absorb and store heat in the evaporative process, cooling itself and the environment in contact with it. This process is most effective during daytime hours; therefore most systems using this principle require integral shading devices.

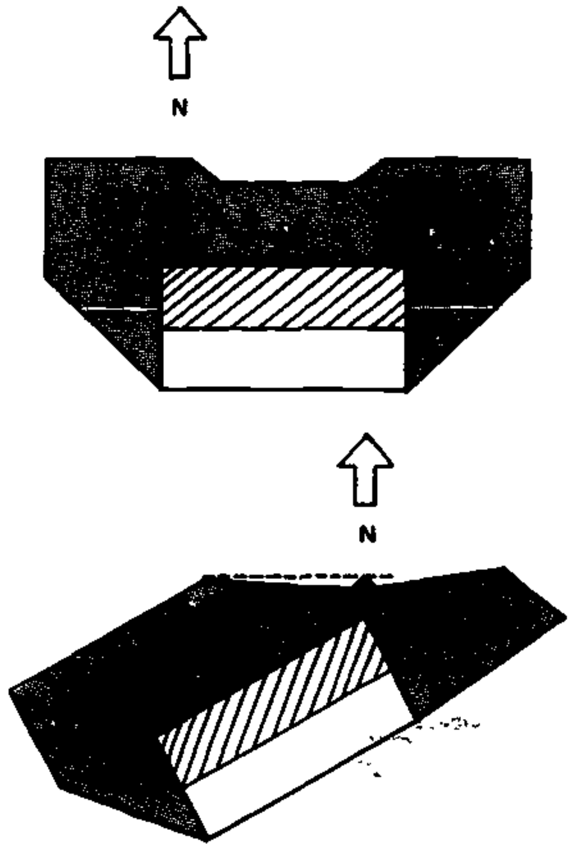
INDIRECT SOLAR ENERGY SYSTEMS—see Active Solar Energy Systems.

LOCAL SOLAR TIME (LOCAL APPARENT SOLAR TIME)—time measured by the actual location of the sun. For example, noon occurs when the sun aligns with the north/south axis of the earth.

MICROCLIMATE—the climate of a specific site or portion of a site. Microclimates result from the overall regional climate as it is affected by local site conditions, including ground slope and orientation, topographic features, elevation, vegetation, winds, water bodies, ground surface, and buildings. These microclimatic influences affect both the heating and cooling requirements of houses and their potential for solar access.

NATURAL COOLING—space cooling alternatives to energy-consumptive central air-conditioning systems. The five principal means of natural cooling are: shading, ventilation, conduction control, radiation, and evaporation.

NORTH PROJECTION—the length of an object's shadow pattern measured along the north/south axis.



THESE DISTANCES ARE THE NORTH PROJECTION OF THE BUILDING SHADOW.

ORIENTATION—the position of an object with respect to true compass points. (See Building Orientation.)

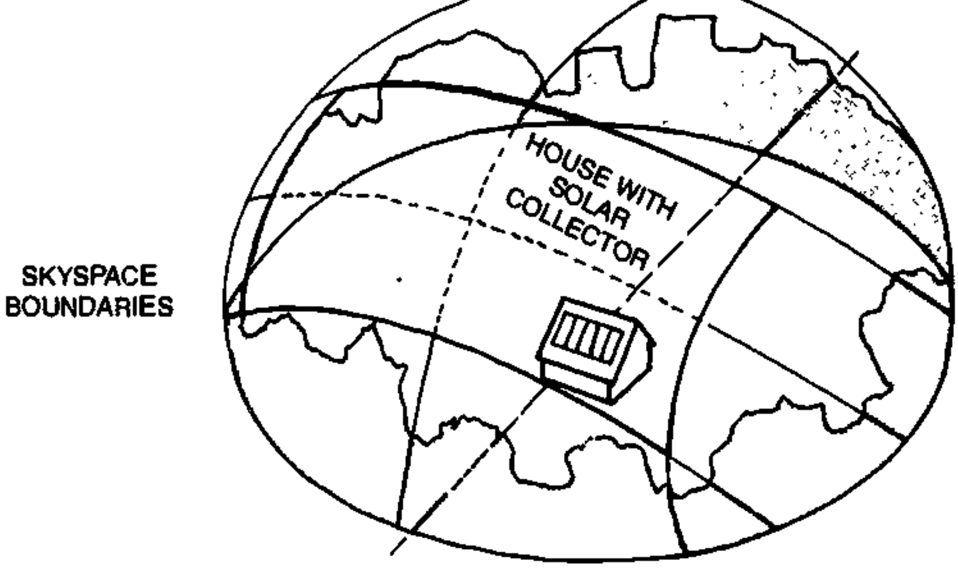
PASSIVE (OR DIRECT) SOLAR ENERGY SYSTEM—a system where the collector and thermal storage components are integrated, requiring no transfer device for solar-heated fluid. A passive systems tends to have less hardware than an active system; it is usually built as an essential component of the building rather than as an addition.

PLANNED UNIT DEVELOPMENT (PUD)—a development planned as a whole, where conventional subdivision regulations (such as type of housing, height limitations, setbacks, densities, and minimum lot sizes) are waived to allow more design flexibility and amenities. This kind of development has greater potential for solar access planning than does conventional development.

RADIATIVE COOLING—cooling provided by warm surfaces radiating excess heat to cool surfaces. Water bodies (roof ponds) and massive construction materials (concrete and stone) absorb heat from interior spaces during daytime hours and radiate it away at night. (See Cold Night Sky and Cool North Sky).

RESTRICTIVE COVENANTS—the most common form of private agreement that can be used to protect solar access; a restrictive covenant is a contract between two or more people which involves mutual promises of reciprocal benefits and burdens among the contracting landowners.

SKYSPACE—that portion of the sky which must remain unobstructed for a collector to operate effectively. Protecting solar access simply means locating objects, such as buildings and trees, where they will not shade a collector's skyspace. Skyspace is specified by using latitude-dependent skyspace angles, which give the sun's position at critical times. Skyspace requirements vary with latitude and the use pattern of the collector.



"Skyspace"—that portion of the sky which must remain unobstructed for a collector to operate effectively.

SOLAR ACCESS—allowing sunlight to strike a solar collector. This is accomplished by locating obstructions, such as buildings and trees, where their shadows will not fall on a collector during critical periods of operation. The concept of skyspace defines that portion of the sky which must remain unobstructed and defines specified critical angles for use in solar planning.

SOLAR ANGLES—angles used to specify the sun's position at a given time. (See Altitude and Azimuth.)

SUN TEMPERED—a building whose long walls and major glazing surfaces are oriented to the south. This maximizes beneficial sunlight warming the building in winter. Overhangs or shading devices shade glazing to minimize unwanted heat gain in summer. Solar tempering can be used to advantage in almost all climates.

SURFACE-TO-VOLUME RATIO—the ratio of exposed surface of a building to occupied volume. A measure of exposure to harsh climate conditions causing unwanted heat loss and heat gain. (Lower numbers are desirable). This ratio is especially useful in evaluating alternative building forms.

THERMAL MASS—any material used to store the sun's heat or the night's coolness. Water, concrete, and rock are common choices for thermal mass. In winter, thermal mass stores solar energy collected during the day and releases it during sunless periods (nights or cloudy days). In summer, thermal mass absorbs excess daytime heat and ventilation allows it to be discharged to the outdoors at night.

THERMOSIPHON—a method of circulating a fluid in which the warmer, less dense portion rises above the cooler. This method can be used in place of pumps to transfer solar-heated water or air.

USE PATTERN—the use pattern of the solar energy system refers to the time when the system is needed. The *daily use pattern* for residences is both day and night, while offices and schools may be used only during daytime hours. The *yearly use pattern*, is related to the function of the solar energy system; for example, space heating is used only during the cold season, while domestic water heating is used all year. The use pattern largely determines the skyspace requirements of the solar energy system.

Appendix II: Skyspace Angles

The recommended 45-degree solar skyspace azimuths are suitable for latitudes up to 40 degrees north. Beyond that, the solar altitudes at the winter solstice (December 21) are too restrictive at the a.m. and p.m. azimuth angles. At 45 degrees north latitude, for example, the a.m. and p.m. solar altitude is 4.4 degrees; at 48 degrees north latitude, the sun is only 2.4 degrees above the horizon at the a.m. and p.m. hours. These low solar altitudes are clearly unsuitable for two reasons: first, solar radiation below 12 degrees altitude is reduced in intensity because the atmosphere itself absorbs radiation before it strikes the collector and second, shadow lengths at the solstice at that latitude would be so great that development on lots to the south of the collector would be unduly restricted.

To define solar azimuths for the higher latitudes, a solar skyspace of 50-degree azimuths for the a.m. and p.m. angles is suggested. At winter solstice, the sun will be more than 12 degrees above the horizon only at azimuths plus or minus 38 degrees (for 45 degrees north latitude) and 32 degrees (for 48 degrees north latitude). As the sun rises higher in the sky in the fall and spring months, however, the wider skyspace angles allow more solar radiation to fall on the collector at times other than around the winter solstice, as the sun's path across the sky describes an arc lying above the critical 12-degree altitude for longer periods of time. This wider skyspace definition would allow usable solar radiation in the spring and fall months, which still have appreciable solar heating requirements as a result of the cooler, northern climate. The site planner, however, must remember that adopting a solar skyspace definition using 50-degree azimuths for the a.m. and p.m. hours allows increased solar access during the entire heating season at these higher latitudes.

If the topography, density, or latitude of a community make a winter solstice period too restrictive, other standards can be adopted. Another important factor is tree foliage. Obviously, a tree with few or no leaves in winter may be full of leaves in the middle of summer. This factor has to be taken into account in using the winter solstice to determine skyspace.

As mentioned earlier, some uses of solar energy do not require that the solar skyspace be based on winter conditions. A solar collector for a cooling system that is used only in the warmer months can have a completely different skyspace requirement than a system used for winter heating. For example, because of the higher collector temperatures needed to evaporate the coolant, cooling systems using absorption cooling mechanisms require a much wider solar skyspace than the 45-degree skyspace defined for winter heating. In that the sun is higher in the sky during the summer months, there is a longer period of time during the day when solar radiation is available to the collector. The longer time period when the sun is above the critical 12-degree altitude results in a skyspace that is defined by much larger azimuths than the 45-degree boundaries of the winter skyspace. Similarly, solar cooling systems using radiation or evaporation as cooling mechanisms may require solar access that encompasses the cool north sky or the entire cool night sky. However defined, this access, if unobstructed, permits the maximum practical amount of sunlight to reach the solar collector over the course of the required period of use.

Figure 106 gives recommended skyspace azimuths and their corresponding altitudes for different latitudes, with the percentages of daily radiation yielded by using those angles.

Figure 106. Recommended Skyspace Angles for December 21

	AM/PM Position*			Percent
N. Latitude	Azimuth	Altitude	Noon Altitude	Radiation***
25°	45°	25°	42°	76%
30°	45°	20°	37°	80%
35°	45°	16°	32°	85%
40°	45°	12°	27°	90%
45°**	(50°)	(12°)	22°	88%
48°**	(50°)	(12°)	18°	87%

*The AM/PM angles presented in this chart are the same for both east of south and west of south. For example, if the skyspace azimuth is 50°, then the protected area goes from 50° east of south to 50° west of south.

**The 50° azimuths are not based on December 21st, but are suggested as a compromise to assure solar access during the entire heating season exclusive of the winter solstice period. Similarly, the 12 degree altitudes apply only to those months when the sun's path is 12 degrees above the horizon within the 50 degree azimuth angles.

***Radiation is based on the percentage of total available radiation falling on a horizontal surface on December 21. Example: If the skyspace between 45° east of south and 45° west of south is protected at 30° latitude, then 80% of the available radiation will strike the collector. If the collector is tilted, then these percentages may be even higher.

Figure 107. Table of Hourly Altitude, Azimuth, and Percent of Available Radiation

This table shows hourly values at varying latitudes for solar altitude, azimuth, and percent radiation falling on December 21. The percent radiation value is the portion of daily solar radiation falling in the hour-long time period one-half hour before and after the time given on the table. For example, for the 2:00 column, it is the percent radiation falling from 1:30 until 2:30. The sum of the hourly values equals approximately 100 percent. This value gives an idea of how much energy a solar collector will be deprived of if shaded during a given time of day.

North Latitude		Time of Day 8	9	10	11	12	1	2	3	4
25°	Alt	14.3	24.8	33.5	39.4	41.6	39.4	33.5	24.8	14.3
	Az	−55.1	−45.6	−33.4	−17.9	0.0	17.9	33.4	45.6	55.1
	% Rad	8.7	11.0	11.9	12.3	12.4	12.3	11.9	11.0	8.7
30°	Alt	11.4	21.3	29.3	34.6	36.6	34.6	29.3	21.3	11.4
	Az	−54.2	−44.1	−31.7	−16.8	0.0	16.8	31.7	44.1	54.2
	% Rad	7.9	11.0	12.1	12.6	12.8	12.6	12.1	11.0	7.9
35°	Alt	8.5	17.7	25.0	29.9	31.6	29.9	25.0	17.7	8.5
	Az	−53.5	−42.9	−30.4	−15.9	0.0	15.9	30.4	42.9	53.5
	% Rad	6.7	11.0	12.5	13.2	13.3	13.2	12.5	11.0	6.7
40°	Alt	5.5	14.0	20.7	25.0	26.6	25.0	20.7	14.0	5.5
	Az	−53.0	−42.0	−29.4	−15.2	0.0	15.2	29.4	42.0	53.0
	% Rad	4.5	11.0	13.2	14.1	14.4	14.1	13.2	11.0	4.5
45°	Alt	2.5	10.2	16.3	20.2	21.6	20.2	16.3	10.2	2.5
	Az	−52.7	−41.2	−28.5	−14.7	0.0	14.7	28.5	41.2	52.7
	% Rad	1.0	10.7	14.4	15.8	16.2	15.8	14.4	10.7	1.0
48°	Alt	.6	8.0	13.7	17.3	18.6	17.3	13.7	8.0	.6
	Az	−52.6	−40.9	−28.2	−14.4	0.0	14.4	28.2	20.9	52.6
	% Rad	0.0	9.7	14.8	16.8	17.3	16.8	14.8	9.7	0.0

Appendix III: Shadow Length Tables and Equation

These tables give the shadow length on December 21 of a one-foot pole for varying latitudes and directions and degrees of slopes. The a.m. and p.m. values correspond to 45 degree azimuths that are used to define the day's period of usable solar radiation. The figures are rounded off, and there may be some errors in shadow length for steeper slopes or taller buildings at 45 degrees and 48 degrees north latitude, where the rounding-off error may be multiplied extensively.

Figure 108. Shadow Length Tables

25° NORTH LATITUDE

	N			NE			E			SE			S			SW			W			NW		
SLOPE	AM	NOON	PM	AM	NOON	PM	AM	NOON	PM	AM	NOON	PM	AM	NOON	PM	AM	NOON	PM	AM	NOON	PM	AM	NOON	PM
0%	2.1	1.1	2.1	2.1	1.1	2.1	2.1	1.1	2.1	2.1	1.1	2.1	2.1	1.1	2.1	2.1	1.1	2.1	2.1	1.1	2.1	2.1	1.1	2.1
5%	2.3	1.2	2.3	2.1	1.2	2.4	2.0	1.1	2.3	1.9	1.1	2.1	2.0	1.1	2.0	2.1	1.1	1.9	2.3	1.1	2.0	2.4	1.2	2.1
10%	2.5	1.3	2.5	2.1	1.2	2.7	1.8	1.1	2.5	1.7	1.0	2.1	1.8	1.0	1.8	2.1	1.0	1.7	2.5	1.1	1.8	2.7	1.2	2.1
15%	2.7	1.4	2.7	2.1	1.3	3.1	1.7	1 1	2.7	1.6	1.0	2.1	1.7	1.0	1.7	2.1	1.0	1.6	2.7	1.1	1.7	3.1	1.3	2.1
20%	3.0	1.5	3.0	2.1	1.4	3.6	1.6	1.2	3 0	1.5	1.0	2.1	1.6	0.9	1.6	2.1	1.0	1.5	3.0	1.2	1.6	3.6	1.4	2.1

30° NORTH LATITUDE

	N			NE			E			SE			S			SW			W			NW		
SLOPE	AM	NOON	PM	AM	NOON	PM	AM	NOON	PM	AM	NOON	PM	AM	NOON	PM	AM	NOON	PM	AM	NOON	PM	AM	NOON	PM
0%	2.7	1.3	2.7	2.7	1.3	2 7	2.7	1.3	2.7	2.7	1.3	2.7	2.7	1.3	2.7	2.7	1.3	2.7	2.7	1.3	2.7	2.7	1.3	2.7
5%	2.9	1.4	2.9	2.7	1.4	3.1	2.4	1.4	2.9	2.4	1.3	2.7	2.4	1.3	2.4	2.7	1.3	2.4	2.9	1.4	2.4	3.1	1.4	2.7
10%	3.3	1.6	3.3	2.7	1.5	3.6	2.2	1.4	3.3	2.1	1.2	2.7	2.2	1.2	2.2	2.7	1.2	2.1	3.3	1.4	2.2	3.6	1.5	2.7
15%	3.7	1.7	3.7	2.7	1.6	4.4	2.1	1.4	3.7	1.9	1.2	2.7	2.1	1.1	2.1	2.7	1.2	1.9	3.7	1.4	2.1	4.4	1.6	2.7
20%	4.3	1.9	4.3	2.7	1.7	5.7	1.9	1.4	4.3	1.7	1.2	2.7	1.9	1.1	1.9	2.7	1.2	1.7	4.3	1.4	1.9	5.7	1.7	2.7

35° NORTH LATITUDE

	N			NE			E			SE			S			SW			W			NW		
SLOPE	AM	NOON	PM	AM	NOON	PM	AM	NOON	PM	AM	NOON	PM	AM	NOON	PM	AM	NOON	PM	AM	NOON	PM	AM	NOON	PM
0%	3.5	1.6	3.5	3.5	1.6	3.5	3.5	1.6	3.5	3.5	1.6	3.5	3.5	1.6	3.5	3.5	1.6	3.5	3.5	1.6	3.5	3.5	1.6	3.5
5%	4.0	1.8	4.0	3.5	1.7	4.2	3.1	1.6	4.0	3.0	1.5	3.5	3.1	1.5	3.1	3.5	1.5	3.0	4.0	1.6	3.1	4.2	1.7	3.5
10%	4.6	2.0	4.6	3.5	1.8	5.3	2.8	1.6	4.6	2.6	1.5	3.5	2.8	1.4	2.8	3.5	1.5	2.6	4.6	1.6	2.8	5.3	1.8	3.5
15%	5.5	2.2	5.5	3.5	2.0	7.2	2.5	1.6	5.5	2.3	1.4	3.5	2.5	1.3	2.5	3.5	1.4	2.3	5.5	1.6	2.5	7.2	2.0	3.5
20%	6.8	2.5	6.8	3.5	2.2	11.4	2.3	1.7	6.8	2.0	1.3	3.5	2.3	1.3	2.3	3.5	1.3	2.0	6.8	1.7	2.3	11.4	2.2	3.5

40° NORTH LATITUDE

	N			NE			E			SE			S			SW			W			NW		
SLOPE	AM	NOON	PM	AM	NOON	PM	AM	NOON	PM	AM	NOON	PM	AM	NOON	PM	AM	NOON	PM	AM	NOON	PM	AM	NOON	PM
0%	4.8	2.0	4.8	4.8	2.0	4.8	4.8	2.0	4.8	4.8	2.0	4.8	4.8	2.0	4.8	4.8	2.0	4.8	4.8	2.0	4.8	4.8	2.0	4.8
5%	5.7	2.2	5.7	4.8	2.2	6.2	4.1	2.0	5.7	3.8	1.9	4.8	4.1	1.8	4.1	4.8	1.9	3.8	5.7	2.0	4.1	6.2	2.2	4.8
10%	7.2	2.5	7.2	4.8	2.3	9.1	3.6	2.0	7.2	3.2	1.8	4.8	3.6	1.7	3.6	4.8	1.8	3.2	7.2	2.0	3.6	9.1	2.3	4.8
15%	9.6	2.9	9.6	4.8	2.6	16.6	3.2	2.0	9.1	2.8	1.7	4.8	3.2	1.6	3.2	4.8	1.7	2.8	9.6	2.0	3.2	16.6	2.6	4.8
20%	14.5	3.4	14.5	4.8	2.8	97.5	2.8	2.0	14.5	2.4	1.6	4.8	2.8	1.5	2.8	4.8	1.6	2.4	14.5	2.0	2.8	97.5	2.8	4.8

45° NORTH LATITUDE

	N			NE			E			SE			S			SW			W			NW		
SLOPE	AM	NOON	PM	AM	NOON	PM	AM	NOON	PM	AM	NOON	PM	AM	NOON	PM	AM	NOON	PM	AM	NOON	PM	AM	NOON	PM
0%	7.2	2.5	7.2	7.2	2.5	7.2	7.2	2.5	7.2	7.2	2.5	7.2	7.2	2.5	7.2	7.2	2.5	7.2	7.2	2.5	7.2	7.2	2.5	7.2
5%	9.6	2.9	9.6	7.2	2.8	11.2	5.7	2.5	9.6	5.3	2.3	7.2	5.7	2.2	5.7	7.2	2.3	5.3	9.6	2.5	5.7	11.2	2.8	7.2
10%	14.6	3.4	14.6	7.2	3.1	25.6	4.8	2.5	14.6	4.2	2.2	7.2	4.8	2.0	4.8	7.2	2.2	4.2	14.6	2.5	4.8	25.6	3.1	7.2
15%	30.3	4.1	30.3	7.2	3.5	—	4.1	2.6	30.3	3.5	2.0	7.2	4.1	1.9	4.1	7.2	2.0	3.5	30.3	2.6	4.1	—	3.5	7.2
20%	—	5.2	—	7.2	4.0	—	3.6	2.6	—	2.9	1.9	7.2	3.6	1.7	3.6	7.2	1.9	2.9	—	2.6	3.6	—	4.0	7.2

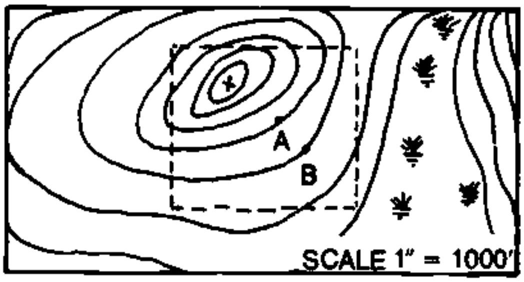
48° NORTH LATITUDE

	N			NE			E			SE			S			SW			W			NW		
SLOPE	AM	NOON	PM	AM	NOON	PM	AM	NOON	PM	AM	NOON	PM	AM	NOON	PM	AM	NOON	PM	AM	NOON	PM	AM	NOON	PM
0%	10.1	3.0	10.1	10.1	3.3	10.1	10.1	3.0	10.1	10.1	3.0	10.1	10.1	3.0	10.1	10.1	3.0	10.1	10.1	3.0	10.1	10.1	3.0	10.1
5%	15.8	3.5	15.8	10.1	3.3	20.5	7.5	3.0	15.8	6.7	2.7	10.1	7.5	2.6	7.5	10.1	2.7	6.7	15.8	3.0	7.5	20.5	3.3	10.1
10%	35.7	4.3	35.7	10.1	3.8	—	5.9	3.0	35.7	5.0	2.5	10.1	5.9	2.3	5.9	10.1	2.5	5.0	35.7	3.0	5.9	—	3.8	10.1
15%	—	5.4	—	10.1	4.4	—	4.9	3.0	—	4.0	2.3	10.1	4.9	2.1	4.9	10.1	2.3	4.0	—	3.0	4.9	—	4.4	10.1
20%	—	7.5	—	10.1	5.2	—	4.2	3.0	—	3.3	2.1	10.1	4.2	1.9	4.2	10.1	2.1	3.3	—	3.0	4.2	—	5.2	10.1

Figure 109. Calculation of Slope Percentage

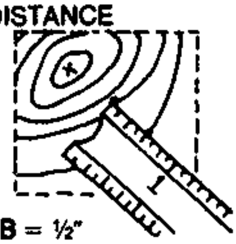
$$= \frac{\text{vertical distance}}{\text{horizontal distance}} = \frac{V}{H} = \text{SLOPE (\%)}$$

PROBLEM — TO FIND SLOPE OF AB



H = 500′

STEP 1:
ESTABLISH
HORIZONTAL
DISTANCE



AB = ½″
since scale is 1″ = 1000′
then:
½ × 1000 = 500
AB = 500′

V = 20′

STEP 2:
ESTABLISH
VERTICAL DISTANCE

Since vertical distance equals the difference between contours, and since contour interval on this map is 20 feet,
then: A − B =
740′ − 720′ = 20′

$$\frac{V}{H} = \frac{20'}{500'} = .04$$

SOLUTION — SLOPE AB = 4%

Source: The Land Book Office of Comprehensive Planning, N.H., 1976

Calculating Shadow Patterns

Shadow patterns may be calculated graphically by formula or by using the shadow length tables. In either case, various shadow lengths for each time of day are laid out on paper and connected to form the final pattern. Below is an example of how to develop a shadow pattern using the shadow length tables in the Appendix.

The example shows how the shadow pattern of a pole is calculated. The pole is used because it is the simplest ground-anchored object that can cast a shadow. More complex objects such as trees or houses can be represented by a composite of poles to calculate their shadow patterns.

Calculating the Shadow Pattern of a Pole

Pole is 30 feet high.

Latitude of location is 40 degrees north.

Pole is on land that slopes to the southeast at a 10 percent grade.

Step 1: From the appropriate table (in this case the 40-degree table) find the shadow length values for a.m., p.m., and noon.

Read the intersection of the columns labeled "S.E." and "10 percent," as indicated on the chart.

40° NORTH LATITUDE

	N			NE			E			SE			S		
SLOPE	AM	NOON	PM	AM	NOON	PM	AM	NOON	PM	AM	NOON	PM	AM	NOON	PM
0%	4.8	2.0	4.8	4.8	2.0	4.8	4.8	2.0	4.8	4.8	2.0	4.8	4.8	2.0	4.8
5%	5.7	2.2	5.7	4.8	2.2	6.2	4.1	2.0	5.7	3.8	1.9	4.8	4.1	1.8	4.1
10%	7.2	2.5	7.2	4.8	2.3	9.1	3.6	2.0	7.2	3.2	1.8	4.8	3.6	1.7	3.6
15%	9.6	2.9	9.6	4.8	2.6	16.6	3.2	2.0	9.1	2.8	1.7	4.8	3.2	1.6	3.2
20%	14.5	3.4	14.5	4.8	2.8	97.5	2.8	2.0	14.5	2.4	1.6	4.8	2.8	1.5	2.8

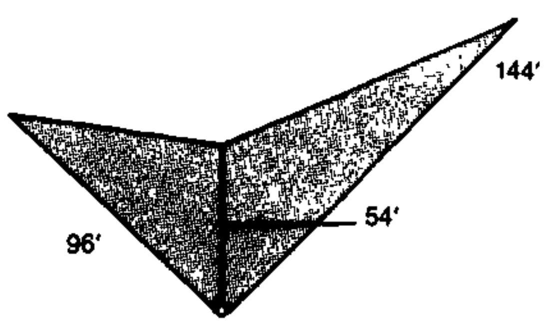
Step 2: The values given in the table are for a one-foot pole, so they must be multiplied by the height of the pole, in this case 30 feet.

a.m. value × pole height = a.m. shadow length
3.2 30 96 feet

noon value × pole height = noon length
1.8 30 54 feet

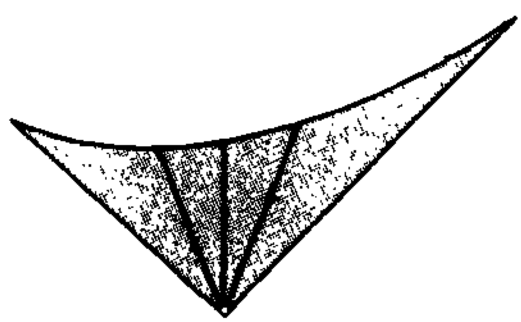
p.m. value × pole height = p.m. length
4.8 30 144 feet

Step 3: Scale the shadow lengths out on paper as viewed from overhead and connect the end points.



45° boundaries of skyspace are used to define area of shadow that will block important sunlight.

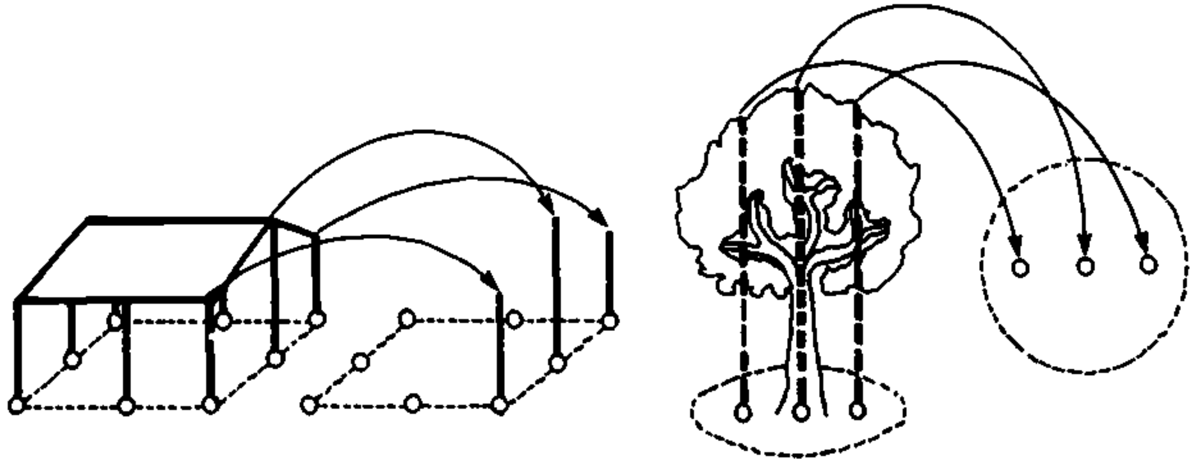
The resulting figure approximates the complete shadow pattern, which, if perfectly plotted, would result in a curve opposite the right angle. If a pattern closer to the true one is desired, additional shadow lengths for other times of the day can be drawn in to fill out the curve.



Determining the Shadow Pattern for a Building or Tree

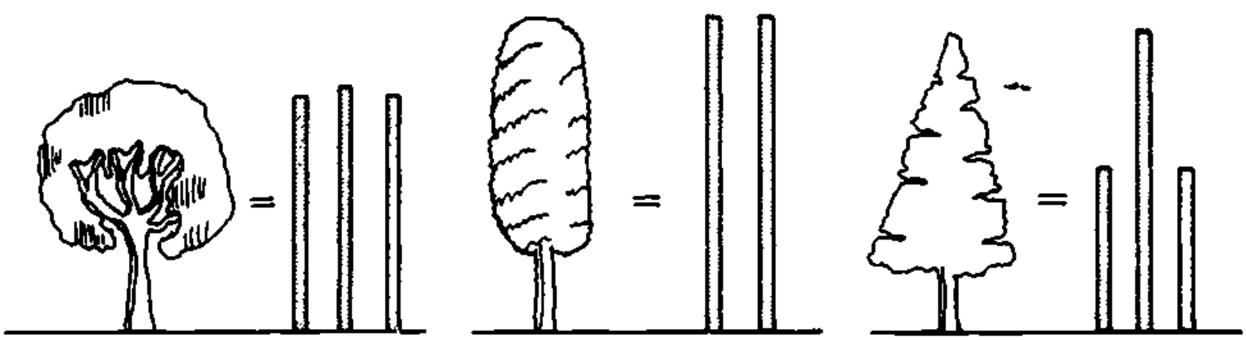
The shadow pattern for a building or tree can be determined in much the same way used to determine the pattern for a single pole, by treating a building or tree as a number of poles, as pictured below.

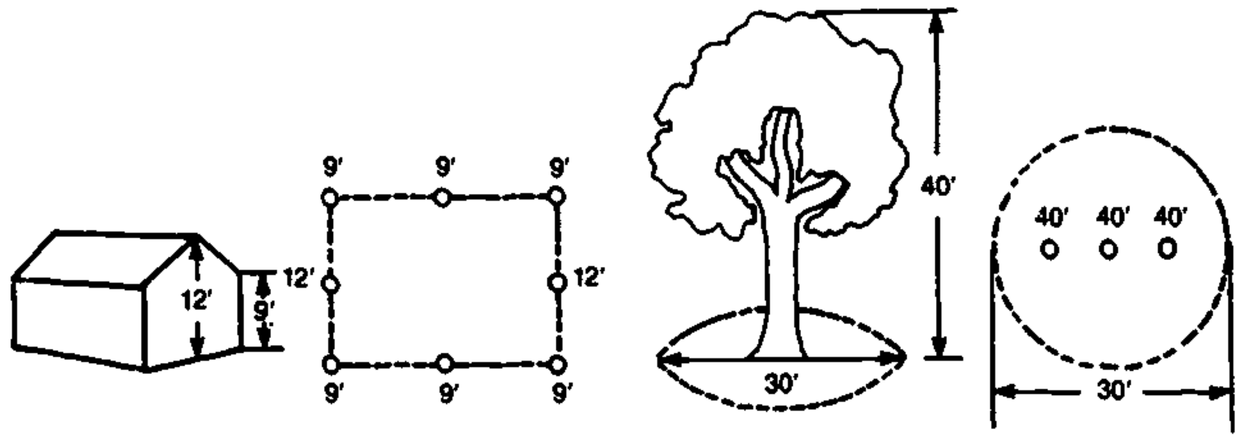
Figure 110. Representing a Building or Tree as Poles



Keep in mind that trees have depth, the same as buildings. For maximum accuracy, therefore, additional poles should be located to the north of the tree crown "centerline." Trees with various common shapes also can be represented by poles of varying heights.

Figure 111. Representing Common Tree Shapes as Poles





The shadow lengths for each pole at the critical times of day are laid out and the composite yields the pattern for the building or tree. The following example shows how this is done for a building and tree simultaneously:

Building is 9′ high at eaves and 12′ high at peak.

Tree is 40′ high and 30′ wide.

Latitude of location is 35° north.

Land slopes to southwest at 15 percent grade.

Step 1: Draw an overhead plan of the building and tree using a series of poles.

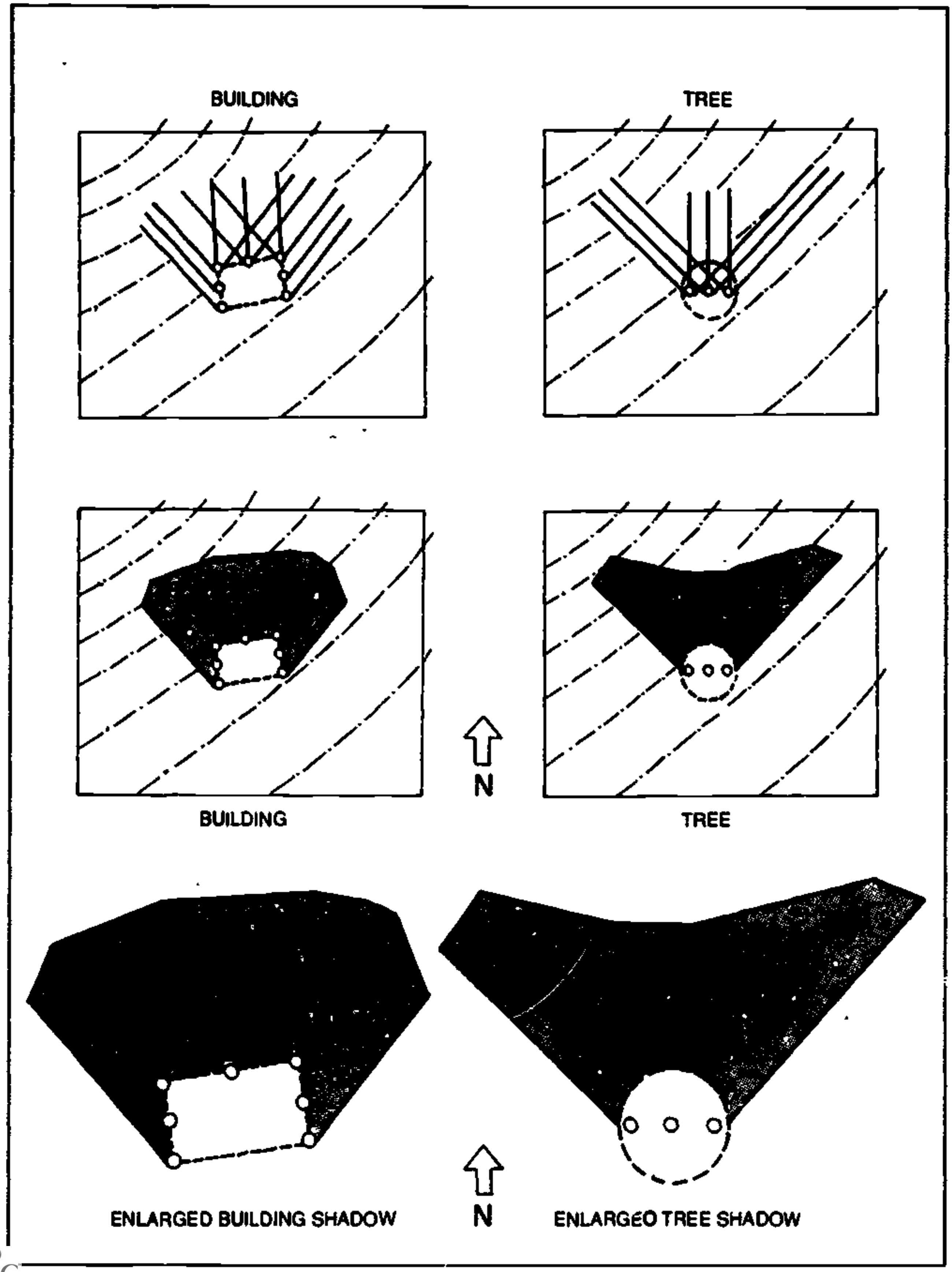
Step 2: From the appropriate table, in this case for 35 degrees, find the shadow length values for a.m., noon, and p.m. They are:

a.m.—2.3 noon—1.4 p.m.—3.5

Multiply the ratios times the height of the poles used in the building and tree examples.

	Height of Pole	Shadow Length A.M.	Noon	P.M.
Building	9′	21′	13′	32′
	12′	28′	17′	42′
Tree	40′	92′	56′	140′

Step 3: Scale the shadow lengths out on the overhead views of the buildings and tree. The boundaries of the skyspace in this case are 45 degrees, so the a.m. and p.m. shadow lengths are laid out at 45 degrees east and west of north. (In a situation where another skyspace angle is used, say 50 degrees, this angle should be used in the shadow pattern.) Finally, connect the end points of the shadow lines for the shadow pattern.


BUILDING
TREE
BUILDING
TREE
N
ENLARGED BUILDING SHADOW
N
ENLARGED TREE SHADOW

Shadow Length Formulas

While the shadow length charts are useful in most situations, they are slightly inaccurate as a result of "rounding off" errors. But what about a community that does not lie directly on an exact latitude shown in the chart, or a site that lies on a south by southeast slope or on a gradient of 12 percent, none of which are shown on the shadow length charts? The following shadow length equations increase the accuracy of the charts, so that planners can develop precise data for local circumstances. For communities where such a high degree of accuracy is not warranted, the approximations shown in the shadow length charts should be sufficient. To achieve maximum accuracy, however, it is necessary to know the exact latitude and the exact solar altitude and azimuths at that latitude. These can be gathered from a *Nautical Almanac* or from the *ASHRAE Handbook of Fundamentals*, published by the American Society of Heating, Refrigeration and Air Conditioning Engineers.

The following abbreviations are used in the equations:

- A_1 = solar altitude
- A_2 = solar azimuth
- H = height of object casting shadow
- S = true shadow length (as shown in cross-section in figure 112, below.
- S_p = plan projected shadow length (the shadow length as shown in a plan view of an object and its shadow; it presumes a distance measured on a hypothetical level surface, instead of the varying irregularities of an actual site as shown in figure 112).
- S_a = slope angle, as described in figure 112.
- S_1 = slope percent/100.

For the simple condition of shadows on a level surface or zero percent slope, the shadow length is given by the formula:

(1) $S = H/\tan(A_1)$

The shadow falls in a direction exactly opposite the numerical direction of the sun:

(2) A_2 shadow = A_2 sun $\pm 180°$

On a sloping surface the shadow length calculation becomes more complex due to the rise or fall of the land. If the land rises in the same direction as the direction of the sun's rays, the shadow will be shortened; if the land falls away, the shadow will be lengthened.

This fact may be expressed mathematically as:

(3) $\text{Fall}_{\text{shadow}} = S_p \times \tan(A_1)$

(4) $\text{Rise}_{\text{land}} = S_p \times \tan(S_a)$
$= S_p \times S_1$

The rise of the land and the fall of the shadow equal the height of the shading object.

(5) $H = \text{fall} = \text{rise}$
$= S_p \times [\tan(A_1) + \tan(S_a)]$

or

(6) $H = S_p \times [\tan(A_1) + S_1]$

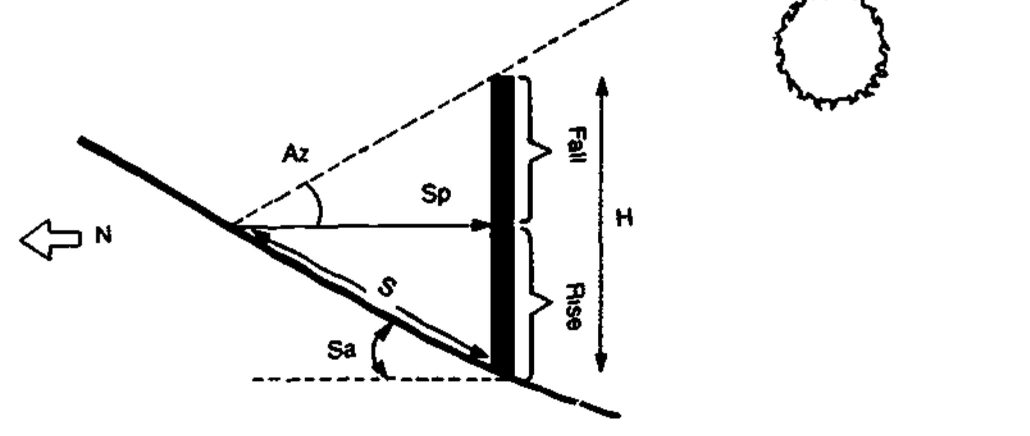
Thus, the plan projected shadow length is:

(7) $$S_p = \frac{H}{[\tan(A_1) + S_1]}$$

But the slope of the land does not usually lie in the direction of the sun's rays. To account for the angle between the sun's rays and the slope of the land, Equation 7 is modified as follows:

(8) $$S_p = \frac{H}{\tan(A_1) + [S \times \cos(A_2 - w)]}$$

Figure 112. Factors in Shadow Length Formula



Appendix IV: Determining Density

Providing solar collectors with unobstructed access to sunlight can affect the density of a development. Buildings can be sited close to one another only to the extent that they do not cast shadows across each other's collector surfaces. This limitation on siting can influence the spacing between structures and the density of the entire project. This angle shows how this spacing can be determined.

Solar access and development density can be reconciled in two ways. First, developers can project density based on local regulations and arrange the development so that shading is minimized. This may mean that some solar access objectives—south-wall protection, for example—are unachievable for some lots if conventional lot layout is used. A developer may have to settle for a less optimal level of solar access in some areas of the development—south-roof protection, for example, instead of south-wall access. Second, the developer can consider solar access as a major development objective and design the project to increase solar access for all lots. This means that the developer essentially works backwards, establishing a solar access objective and then tailoring the project to meet this objective and deriving a project density in the process. In many cases, however, the density that results from trying to achieve a solar access objective may exceed the density permitted under zoning regulations.

Three development conditions can arise in solar access design. The first condition occurs when south-wall access is the major development objective and a development is designed to provide this level of access to all lots. The density of such a development can be determined by using the concept of north shadow projection, discussed earlier in Preliminary Site Planning.

The second condition arises when only roof access alone is considered. A similar analytical process is used for roof access as is used for south-wall access, except that the north shadow projection must be drawn in cross-section to evaluate potential conflicts.

Finally, developments considering either south-wall or south-roof access can be sited on terrain that slopes to the east and west. In determining density in these cases, the technique of developing shadow patterns (based on shadow length data) is most appropriate.

The three development conditions and the three different techniques for determining density are discussed below.

Density and South-Wall Access

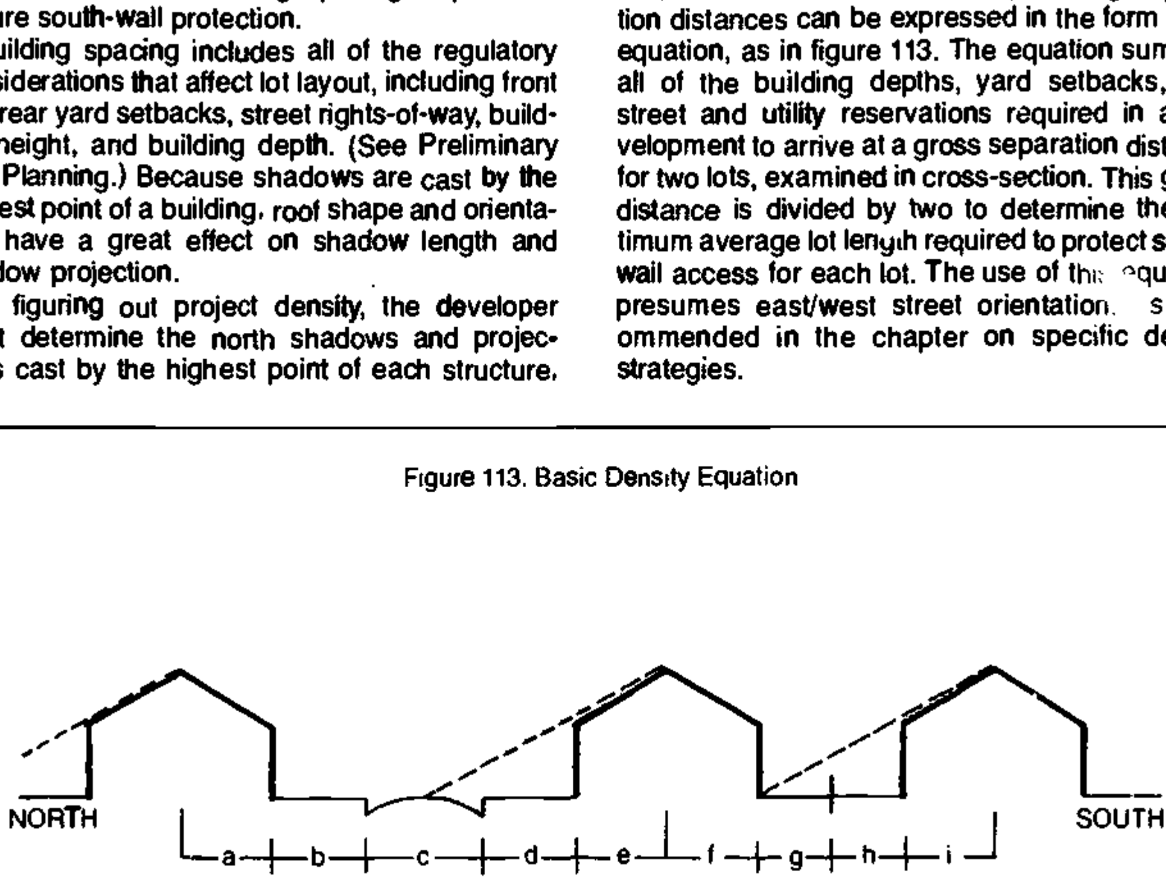
South-wall access is the best level of access for most developments. It is highly recommended for most residential projects. To determine the theoretical project density, determine the site latitude, slope direction, and slope gradient, all of which affect shadow length; then use the shadow projection technique to determine building spacing in a project. Project density can be derived from the minimum building spacing required to assure south-wall protection.

Building spacing includes all of the regulatory considerations that affect lot layout, including front and rear yard setbacks, street rights-of-way, building height, and building depth. (See Preliminary Site Planning.) Because shadows are cast by the highest point of a building, roof shape and orientation have a great effect on shadow length and shadow projection.

In figuring out project density, the developer must determine the north shadows and projections cast by the highest point of each structure, then separate the buildings to make sure that south walls are not shaded. The easiest way to do this is to measure the greatest distance north a shadow may reach on December 21 and compare this shadow projection length to the separation distance. If greater separation is necessary, lots can be lengthened to increase the distance between buildings. This change in lot length to protect solar access may affect the project's density.

To arrive at a gross separation distance for two lots, examined in cross-section, building separation distances can be expressed in the form of an equation, as in figure 113. The equation sums up all of the building depths, yard setbacks, and street and utility reservations required in a development to arrive at a gross separation distance for two lots, examined in cross-section. This gross distance is divided by two to determine the optimum average lot length required to protect south-wall access for each lot. The use of this equation presumes east/west street orientation, as recommended in the chapter on specific design strategies.

Figure 113. Basic Density Equation



$$\frac{a+b+c+d+e+f+g+h+i}{2} = \text{Minimum Gross Lot Length Along North/South Axis (including streets)}$$

where

- a = distance south of building's high point (for flat roof a = 0)
- b = front yard setback
- c = road width
- d = b front yard setback (in full)
- e = distance north of building's high point (for flat roof e = building length along north/south axis)
- f = a
- g = rear yard setback
- h = g (in full)
- i = e (in full)

To use the basic density equation for south-lot access, the north shadow projection for each dwelling must also be used. Where the building spacing exceeds the north shadow projection distance, south-wall access can be protected. But when the separation distance is less than the north shadow projection, the building spacing must be increased by lengthening the lot in the cross-section analysis. The lot length must be increased by the distance that the north shadow projection exceeds the building separation distance, allowing the developer to substitute north shadow projection for one or more of the variables examined in the basic density equation. By making this substitution, the total lot length is also increased by this same distance.

If the building's shadow projection length (L) is longer than either a+b+c+d or f+g+h, then the shadow projection length must be substituted for these groups of factors.

Where L is greater than a+b+c+d, substitute L for a+b+c+d in the basic density equation. Where L is greater than f+g+h, substitute L for these factors. Finally, when L is greater than both a+b+c+d and f+g+h, then substitute L for both sets of factors. In this situation, the basic density equation becomes:

$$\frac{L+e+L+i}{2}$$

= minimum average lot length along north/south axis.

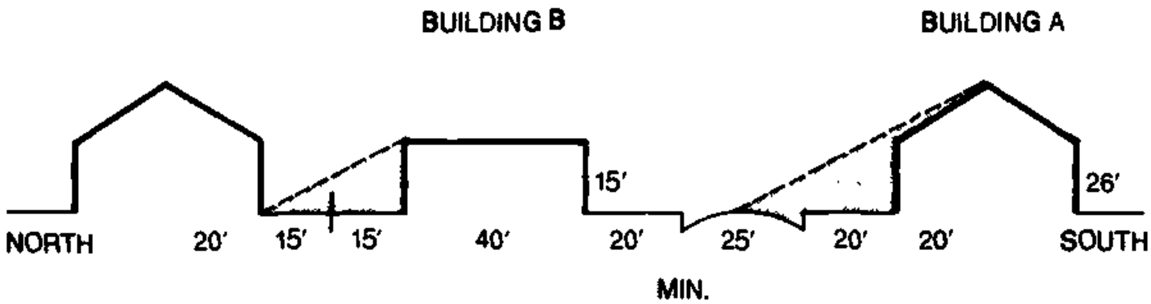
Once the minimum average lot length is determined, then the lot length is multiplied by the lot width to get the total lot area (in square feet). The lot area is then divided into 43,560 square feet (the number of square feet in an acre) to obtain the density, expressed as lots per acre.

Example 1—South-Wall Access

Find building spacing and overall density while providing solar access to the south wall.

Latitude 40° N, 10% south slope, 70' lot width. Minimum setbacks, road width, and building size shown below.

Figure 114. South-Wall Access Example



Ratio of building height to shadow length = 2.5 (from table).

Building A shadow length = L_A = 26' (2.5) = 65'

Building B shadow length = L_B = 15' (2.5) = 37.5'

$$a+b+c+d = 20'+20'+25'+20' = 85'$$

$$85' > L_A$$

$$f+g+h = 0'+15'+15' = 30'$$

$$L_B > 30'$$

Use:

$$\frac{a+b+c+d+e+L_B+i}{2} = \frac{85'+40'+37.5'+20'}{2}$$

91.2' minimum lot length along N/S axis

91.2' length × 70' width = 6387.5 sq. ft. per lot

$$\frac{43560 \text{ sq. ft. per acre}}{6387.5 \text{ sq. ft. per lot}} = 6.8 \text{ lots per acre}$$

Rooftop Access and Density

Rooftop access generally allows greater density than south-wall access. Buildings of the same height will not shade one another's rooftops, if vegetation is controlled. Therefore, buildings can be packed closer together without affecting rooftop access.

Problems can arise, however, in a mixed-use development or a PUD incorporating single-family detached and taller multifamily structures. If the taller structures are located to the south of the lower, single-family detached buildings, then rooftop access of the lower structures can be obstructed. A similar problem may occur when a residential development borders a high- or mid-rise district to the south, where off-site structures can obstruct solar access to buildings within the development.

To analyze shading in these areas and to determine project density, a slightly different technique is used than is used for south-wall access. In the case of rooftop access, north shadow projection must be drawn in cross-section as in figure 115. The shadow projection distances are compared with building separation distances. Structures to the north are moved as far southward as possible, so that the morning and afternoon shadows fall just at the roof eaves. This distance represents the closest packing of buildings on the site, and the optimum lot length, when setbacks and yard requirements are considered. As with south-wall access, the lot width is multiplied by the optimum lot length to determine lot area, and this figure divided into acreage in square feet for a density determination.

This method uses the basic density equation developed for south-wall access. The method is to draw the north projection of Building A.

Then the next building to the north (Building B) is positioned as close to Building A as possible without obstructing solar access to B. (See figure 116.)

The distance from the northerly high point on Building A to the roof edge of Building B is termed L_{AR} and is used as L_A in this example. The minimum spacing distance from Buildings B and C is termed L_{BR}, which is determined and used in the same manner as L_{AR}.

Figure 115. Shadow Projection for Rooftop Access

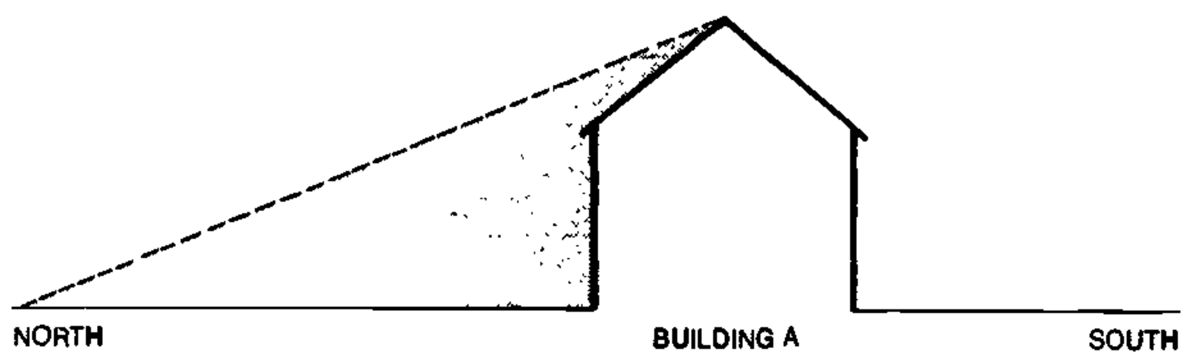


Figure 116. Density and Rooftop Access

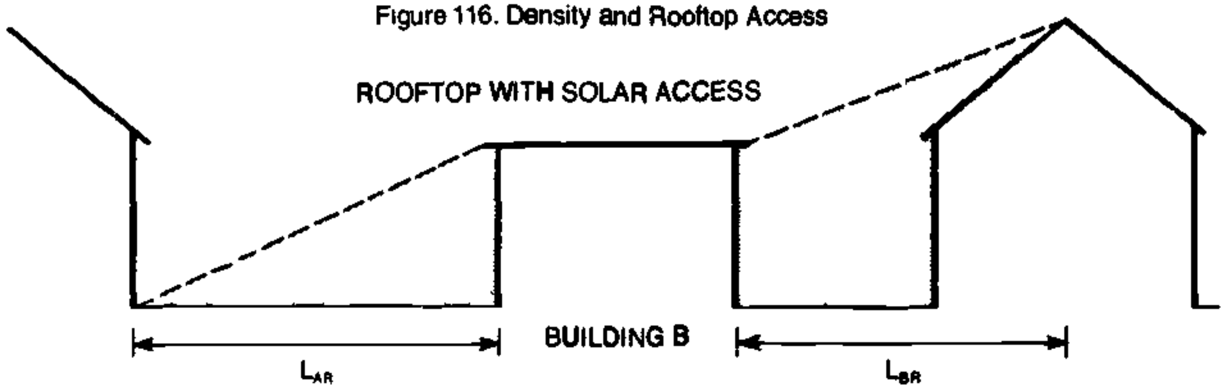
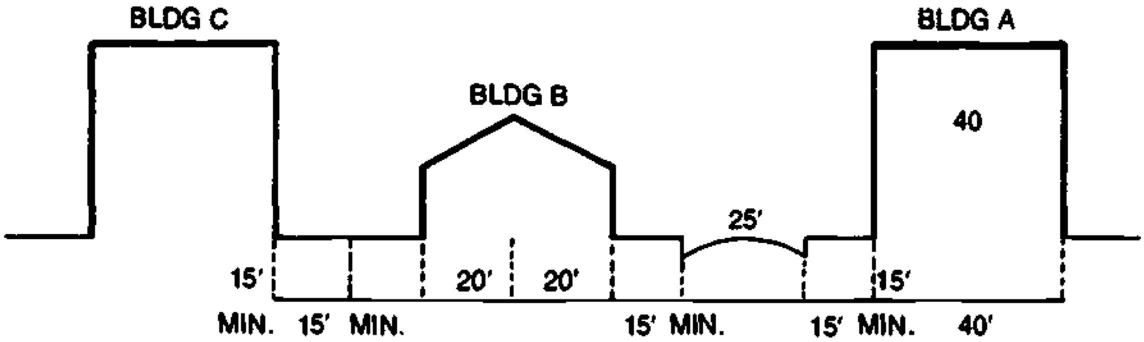


Figure 117. Rooftop Access Example

Find building spacing and overall density with rooftop solar access. Latitude 45°N, 5% south slope, 75′ lot width. Minimum setbacks, road width and building size shown below.



Building B will not shade the roof of Building C. Therefore, only the shadow of Building A will be drawn.
Ratio of shadow length to building height = 4.1 (from figure 54)

$$L_A = 40' (4.1) = 164'$$

Using the basic density equation:

$$a+b+c+d = 0+15'+25'+15' = 55'$$

$$L_{AR} > 55'$$

Use:

$$\frac{L_{AR}+e+f+g+h+i}{2} = \frac{164+20+20+15+15+40}{2} =$$

137′ minimum average lot length along north/south axis 75′ width x 137′ length = 10275′ average sq. ft. per lot

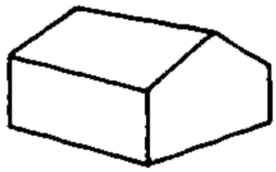
$$\frac{43560 \text{ sq. ft. per acre}}{10275 \text{ sq. ft. per acre}} = 4.2 \text{ lots per acre}$$

Density and East/West Slopes

Determining density where slopes do not run north/south requires more detailed graphic work. Since the shadow pattern of a building on a cross slope is asymmetrical, building layouts must be determined in plan for south-wall access (or in plan and cross-section for rooftop access) before the calculations can be made.

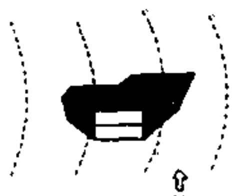
Find building spacing and overall density for an east-facing slope of 15% latitude 35°N. Provide solar access to the south wall of all buildings.
Using the method given in Preliminary Site Planning the shadow of a typical building can be drawn.

Figure 118. Typical Building Dimensions



The following sketch was prepared as the calculations were made.

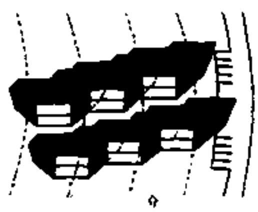
Figure 119. Topographic Contours



Referring to the Shadow Length Tables in Appendix III: The AM shadow length for 10′ = 25′; for 14′ = 35′.
The noon shadow length for 10′ = 16′; for 14′ = 22′.
The PM shadow length for 10′ = 55′; for 14′ = 77′.

Having the shadow pattern for an individual building, this can be shifted about until a group of buildings and their access road have been laid out. Maximum densities can be achieved by an irregular plan such as that given below.

Figure 120. East/West Slope Density Example



Once the plan has been "roughed out," densities can be calculated directly as the number of units per acre.
For the cluster shown the overall area is 225′x140′ = 31500 sq. ft.

Average sq. ft. per unit = $\frac{31500}{6}$ = 5250 sq. ft.

$\frac{43560 \text{ sq. ft./acre}}{5250 \text{ sq. ft./unit}}$ = 83 units/acre

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